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BEST AVAILABLE TECHNOLOGY FOR THE ONTARIO PETROLEUM REFINING SECTOR

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BEST AVAILABLE TECHNOLOGY FOR THE ONTARIO PETROLEUM REFINING INDUSTRY

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The report consists of three parts:

Part I:	Best Available Treatment Technology for the Petroleum Refining Sector
Part II:	Status of Wastewater Generation and Treatment in Ontario Petroleum Refineries
Part III:	Best Available Technology Options For Treatment Of Chlorinated Dibenzo-P-Dioxins and Chlorinated Dibenzofurans in Ontario Petroleum Refinery Catalytic Reforming Wastewaters

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PART I

BEST AVAILABLE TREATMENT TECHNOLOGY FOR THE ONTARIO PETROLEUM REFINING SECTOR

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INTRODUCTION

The Ministry of Ontario established the Municipal-Industrial Strategy for Abatement (MISA) Program in 1986 with an ultimate goal to achieve "virtual elimination" of the discharge of persistent toxic pollutants. To advance toward that goal, the Ministry will establish a series of sector-specific best available technology economically achievable or BAT(EA) effluent limits regulations aimed at reducing, and where possible, eliminating the discharge of toxic and other pollutants. These effluent limitations will be based upon the actual or anticipated performance of a combination of process changes, in-plant and end-of-pipe treatments, and source control measures.

The Ministry recognizes the following criteria for establishing BAT(EA):

- Changes in production processes and raw materials that would eliminate or minimize introduction or formation of toxic chemicals;

- Internal process recycle or reuse of waste materials to minimize or eliminate raw wastewater loadings of toxic pollutants;

- Treatment and recycle of process wastewaters to minimize the mass loadings of toxic pollutants requiring end-of-pipe treatment; and,

- End-of-pipe wastewater treatment to minimize or eliminate the mass discharge of toxic pollutants and to eliminate effluent toxicity to aquatic life.

In response to the Ministry's directive, this document addresses best available technology (BAT) and cost data for the Petroleum Refining Sector. The report provides discussions of the following:

- Petroleum Refinery Wastewater
- Available Treatment Technologies
- Best Available Technology
  (in Ontario, in Canada-outside Ontario, and outside Canada)
- Performance Assessment of Technologies
- Identification of BAT Options for Ontario
- Cost Estimates for the BAT Options

NOTE:
Supplement information is provided in part two and three of this document:

Part 2: Status of Wastewater Generation and Treatment in Ontario Petroleum Refineries (SAIC/APOGEE RESEARCH International, May 1991)

Part 3: Best Available Technology for Treatment of Chlorinated Dibenzo-p-Dioxins and Chlorinated Dibenzofurans - Ontario Petroleum Refinery Catalytic Reforming Wastewaters (SAIC/Amendola Engineering, August 1991)

1.0 PETROLEUM REFINERY WASTEWATER

Wastewaters from petroleum refinery operations originate from crude oil un-loading, refinery processing, non-contact cooling, and from storm water run-off. The following subsections describe each operation and their associated wastewaters.

1.1 CRUDE OIL UNLOADING

Crude oil unloading operations generate ballast wastewater from oil tankers which is contaminated with dissolved salts, oils and other organic constituents. At most refineries where crude oil is received by tanker, ballast water is transferred to holding ponds or holding tanks for primary oil separation and equalization prior to mixing with refinery process wastewaters for further treatment (Barnes, 1984).

1.2 REFINERY PROCESS WASTEWATER

1.2.1 Crude Oil and Product Storage

Petroleum refineries require storage facilities for both crude oil and individual final products. The crude oil storage area of a refinery serves to provide a working supply, equalize process flow and separate water and suspended solids from the crude oil.

During storage, water and suspended solids in products tend to settle out to form a water layer at the tank bottom. Tank cleaning operations constitute a significant source of oily wastewater from storage tanks. Wastewaters associated with crude oil and product storage are typically high in oil, suspended solids and COD.

1.2.2 Crude Oil Desalting

The crude oil desalting process is a pretreatment step to remove the various dissolved salts contained in crude oil. This salt must be removed to avoid problems in subsequent processing operations. Wastewater produced by desalting contains emulsified and free oils, ammonia, phenols, sulfides, suspended solids and dissolved solids.

1.2.3 Crude Oil Distillation

Distillation is the basic refining process for the separation of crude petroleum into intermediate fractions of specified boiling-point ranges. This separation or fractionation takes advantage of the differing boiling points and vapor pressures of the various components in the crude oil mixture.

In addition to the atmospheric distillation process, it is normally necessary to subject the residual or bottoms from atmospheric distillation to a second and/or third stage distillation, conducted under vacuum. The vacuum is usually produced by steam jet ejectors, which are essentially venturi jets with a connection to the throat of the jet that draws vapor from the connected medium. The vapor stream drawn into the jet will contaminate the steam and produce a contaminated condensate. The steam applied for steam stripping in vacuum columns also produces a contaminated condensate.

1.2.4 Refinery Processing

Unit processes are used in varying combinations at petroleum refineries. Generally, a simple petroleum refinery includes catalytic reforming and treating processes in addition to crude oil distillation. A more complex refinery also includes catalytic cracking, polymerization, alkylation and asphalt oxidation as well as other selected unit processes. A very complex refinery may include high vacuum fractionation, solvent extraction, deasphalting, dewaxing and treating processes, in addition to those processes found in simple and complex refineries.

The sources of process wastewater within a refinery include the following:

- Non-segregated cooling water
- Cooling tower blowdown
- Boiler blowdown
- Oily process water
- Sour water
- Water treatment system blowdown
- Air pollution control equipment blowdown

Non-segregated cooling water is once through cooling water which has been combined with other wastewater within the refinery. This is a typical source of process wastewater in old refineries, where the cooling water has become contaminated in the cooling process. Contamination typically includes a low concentration of oil and grease. However, because of the large volume of flow, the mass of pollutants can be substantial.

Boiler blowdown is the concentrated wastewater discharge from a boiler-type heating and steam-generating system. The volume of boiler blowdown is typically small compared with that of cooling towers. Boiler blowdown, as a source of process wastewater, is common in the refining industry.

Oily process wastewater includes the following:

- Contact process water: water contaminated by process utilization
- Non-sour process condensate: the condensate produced in process operations which is not highly contaminated by ammonia and hydrogen sulphide
- Vent scrubber water: the wastewater generated in the control, or scrubbing, of process vent gases
- Tank drainage: the waste material from storage facilities which is collected in the refinery's sewer system
- Flare seal water blowdown: the wastewater from the liquid seal for the waste gas combustion
- Laboratory drainage: the waste produced in the analytical operations of product testing and control
- Maintenance decontamination water: the wastewater generated in the cleanup operations associated with equipment maintenance
- Pad wash water: the washdown wastewater generated in the area of equipment pads.

A refinery typically generates oily process wastewater that is some combination of the individual sources listed above.

Sour water is process wastewater which is contaminated with ammonia and hydrogen sulphide. This is a common type of wastewater in a refinery and generally represents between 8 and 18% of the total process wastewater generated (Barnes, 1984). Sources of sour water include the crude desalter, the crude unit and the desulphurization, catalytic cracking and gas recovery processes.

Water treatment system blowdown is the wastewater discharged from a refinery's fresh water treatment facility. The need for water treatment is dependent on the quality of fresh water available to the refinery.

Air pollution control equipment blowdown is the wastewater discharge from exhaust gas scrubbers in refineries which require control of emissions from combustion processes. This is a source of wastewater in larger refineries.

1.3 PROCESS COOLING WATER

The available options for process cooling in refineries are once through cooling water (OTCW) systems, recirculating cooling water systems, air cooling, and combinations of the above.

Aside from site-specific thermal discharge considerations, the primary wastewater concerns associated with the discharge of once through cooling waters arise from the use of slimicides and biocides to control fouling on heat transfer surfaces. Chlorine

and chlorine derivatives are the principal chemicals used as OTCW additives. Other principal concerns associated with once through cooling water systems are the potential for significant pollutant discharges resulting from process equipment leaks, and thermal shock to fish during start-up and shut-down.
Similarly, depending upon the chemicals used to minimize fouling and corrosion, treatment of recirculating non-contact cooling waters can also result in the discharge of toxic pollutants.

Air cooling systems can operate using air as the non-contact cooling fluid. However, most air cooling systems use air to cool the water (in a closed loop system) which in turn cools the process unit. No wastewater is generated from these air cooling systems.

1.4 STORM WATER

Storm water run-off can contribute significantly to the generation of wastewater in refineries. It may be contaminated or uncontaminated dependent upon the run-off source area. In general, storm water from immediate process areas is contaminated and must be treated. In developed areas outside of the process area, storm water is often collected, tested, and treated as necessary. In undeveloped areas, storm water often is discharged directly.

2.0 AVAILABLE TREATMENT TECHNOLOGIES

Available treatment technologies for refinery wastewater are classified into the following four categories within this section: in-plant technologies; end-of-pipe treatment technologies; advanced treatment technologies; and, pollution prevention measures.

2.1 IN-PLANT TREATMENT TECHNOLOGIES

In-plant technologies for refinery wastewater include steam stripping, neutralization, catalytic reformer wastewater treatment, and chemical precipitation. Table 1 summarizes the available in-plant treatment technologies for the wastewater generated from specific refinery operations.

2.1.1 Steam Stripping

Sour waters generally result from water brought into direct contact with a hydrocarbon stream. This occurs when steam is used as a stripping or mixing medium, or when water is used as a washing medium, as in the crude desalting unit. Sour waters contain sulfides, ammonia and phenols.

The most common in-plant treatment schemes for sour waters involve sour water stripping. Sour water stripping is a gas-liquid separation process that uses steam or flue gas to extract the gases (sulfides and ammonia) from the wastewater. The stripper itself is a distillation-type column containing either trays or packing material. Columns range from simple one-pass systems to sophisticated reflux columns with reboilers

In removing sulfides and ammonia, the efficiency of sour water treatment processes is greatly influenced by pH. In general, sour water strippers remove between 85 and 99% of the sulfides present. However, when the pH is lowered by means of acid treatment, stripping efficiency is increased. On the other hand, when caustic is utilized to maintain high pH, up to 95% ammonia removal can be achieved. By considering pH in the stripping process, one can either adjust the pH to optimize removal of both sulfides and ammonia, or use a two-stage sour water stripping process to obtain maximum removal of both pollutants (Barnes, 1984).

Steam stripping can also be used to remove volatile organic compounds from selected refinery wastewater streams that have high concentrations of these pollutants. Stripping of the organic constituents of the wastewater stream occurs because the organic volatiles tend to vaporize into the steam until its concentration in the vapor and liquid phases (within the stripper) are in equilibrium. The height of the column and the amount of packing material and/or the number of metal trays along with steam pressure in the column generally determine the amounts of volatiles that can be removed and the effluent pollutant levels that can be attained by the stripper.

TABLE 1

AVAILABLE DEMONSTRATED WASTEWATER TECHNOLOGIES
FOR IN-PLANT TREATMENT OF REFINERY PROCESS WASTEWATERS

REFINERY OPERATION	AVAILABLE TECHNOLOGIES
Crude Desalting	Sour water stripping for removal of ammonia and sulfides.
Atmospheric and Vacuum Distillation	Sour water stripping. Sour water can be recycled through crude desalters prior to processing in sour water strippers.
Thermal Cracking	Sour water stripping
Catalytic Cracking	Sour water stripping
Hydrocracking	Sour water stripping
Polymerization	Neutralization
Alkylation	Acid recovery; neutralization.
Isomerization	Generally not pre-treated.
Catalytic Reforming	Neutralization; Granular activated carbon for removal of CDDs/CDFs.
Solvent Refining	Generally not pre-treated.
Hydrotreating	Generally not pre-treated.
Grease Manufacturing	Generally not pre-treated.
Drying and Sweetening	Neutralization with acid or FCCU regenerator flue gas.
Lube Oil Finishing	Generally not pre-treated.
Blending and Packaging	Generally not pre-treated.
Equipment Cleaning; Spills; Miscellaneous.	Segregation; slop oil tank.
Utilities	Equalization of ion exchange regeneration wastes; others generally not pre-treated.

After the volatile pollutant is extracted from the wastewater into the superheated steam, the steam is condensed to form two layers of generally immiscible liquids, the aqueous and volatile layers.

Steam strippers are designed to remove individual volatile pollutants based on a ratio (Henry's Law Constant) of their aqueous solubility (tendency to stay in solution) to vapor pressure (tendency to volatilize). The column height and diameter, amount of packing or number of trays, the operating steam pressure, and temperature of the heated feed (wastewater) are varied according to the strippability (using Henry's Law Constant) of the volatile pollutants to be stripped. Volatiles with lower Henry's Law Constants require greater column height, more trays or packing material, greater steam pressure and temperature, more frequent cleaning, and generally more careful operation than do volatiles with higher strippability.

2.1.2 Neutralization of Spent Acids and Caustics

Spent caustic solutions are generated by various finishing wet treatment processes aimed at neutralizing and extracting acidic materials occurring naturally in crude, acidic products from various chemical treatment steps, and acidic materials produced in cracking processes. Spent caustics generally contain sulfides, mercaptans, sulfates, sulphonates, phenols and naphthenic acids. The phenol concentrations, in particular, may be high enough to warrant processing of spent caustics for the recovery of phenols.

It is common practice in many refineries to neutralize spent caustic with spent acid from sulfuric acid alkylation and charge the neutralized solution to a sour water stripper. If the bottoms are then sent to crude desalting, the high phenol content may be recovered within the process by extraction.

2.1.3 Catalytic Reformer Wastewater Treatment

Data from Ontario and U.S. refineries indicate that chlorinated dibenzo-p-dioxins (CDDs) and chlorinated dibenzofurons (CDFs) are found in wastewaters from catalytic reforming operations. The most effective means to achieve minimum mass discharge of these compounds is to isolate and treat the low volume catalytic reforming wastewaters prior to mixing with other refinery process or cooling waters, or stormwaters.

Technologies for removal of CDDs and CDFs include membrane separation (electrodialysis, reverse osmosis), adsorption on granular activated carbon, and solvent extraction.

Electrodialysis and reverse osmosis are widely used in the pharmaceutical, pesticides and chemical process industries as well as in a number of other industries to perform separations of chemical species of varying molecular weight. Membranes may also be available to separate CDDs and CDFs from aqueous solutions, however, none are in use in this mode today.

Adsorption on granular activated carbon offers several advantages over membrane technologies for removal of CDDs and CDFs from catalytic reforming wastewaters. The technology is suitable for relatively large volumes of wastewaters. Aside from spent carbon, there are no by-product sludges or concentrated aqueous streams requiring further processing or treatment for ultimate disposal.

CDDs and CDFs are highly soluble in aromatic solvents. The standard analytical procedure for CDDs and CDFs in aqueous matrices includes a lengthy solvent extraction using benzene. Similar techniques could be applied to remove CDDs and CDFs from catalytic reforming wastewaters, however, there are no such systems currently in service (SAIC/Amendola Engineering, August 1991).

2.2 END-OF-PIPE TREATMENT TECHNOLOGIES

All wastewater treatment that immediately follows the API or oily water separator is considered end-of-pipe treatment. (The API separator is recognized as part of the refinery process equipment for the economic recovery of oil and, as such, is not considered a treatment unit.) Conventional end-of-pipe treatment technologies are addressed in this section and are classified as preliminary, biological, and effluent polishing.

2.2.1 Preliminary Treatment

Preliminary treatment commonly consists of equalization, followed by chemical treatment and supplemental oil removal. Filtration may also be included as part of the preliminary treatment system to limit the loading of solids to downstream units.

Equalization is one of the first, and one of the most important steps in the treatment of wastewater. Fluctuations in contaminant concentrations are levelled and the flow and pH of the waste stream are adjusted to provide the optimum conditions for further treatment. Unusually high flows or high contaminant concentrations, which cannot be handled by equalization, may be diverted to auxiliary holding facilities and slowly re-introduced in the treatment system when conditions warrant.

For refineries in colder climates, the wastewater temperature can be adjusted through direct steam injection or indirect steam treatment to provide ideal biological treatment during cold weather months.

Supplemental oil removal can be accomplished by using parallel plate separators or chemically-assisted dissolved air flotation (DAF) units, whereby emulsified oil in the waste stream is dispersed and the free oil is removed. A parallel plate separator is a device which is very similar to the API separator. It was developed to improve oil and solids removal by mounting parallel plates at an angle along the length of the separator. By vastly increasing surface and floor area, this device permits more efficient collection of oils and solids.

Dissolved air flotation consists of saturating a portion of the wastewater feed, or a portion of the feed or recycled effluent from the flotation unit, with air. The wastewater or effluent recycle is held at this pressure, typically for 1 to 5 minutes, in a retention tank and then released at atmospheric pressure to the flotation chamber. The sudden reduction in pressure results in the release of microscopic air bubbles which attach themselves to oil and suspended particles in the wastewater in the flotation chamber. This results in agglomerates which rise to the surface to form a froth layer.

Induced air flotation (IAF) is similar to DAF systems, but IAF adds air to a flotation tank by using impellers rather than by adding dissolved air to a recirculation tank.

Chemical flocculating agents, such as salts of iron and aluminum, with or without organic polyelectrolytes, are often helpful in improving the effectiveness of the air flotation process and in obtaining a high degree of clarification.

Chemical precipitation can be used to remove metals from selected refinery wastewater streams, such as cooling tower blowdown. Most metals are relatively insoluble as hydroxides, sulfides, or carbonates, and can be precipitated in one of these forms. The sludge formed is then separated from solution by physical means such as sedimentation or filtration. Hydroxide precipitation is the conventional method of removing metals from wastewater. Most commonly, caustic soda (NaOH) or lime ($Ca(OH)_2$) is added to the wastewater to adjust the pH to the point where metal hydroxides exhibit minimum solubilities and are thus precipitated. Sulfide precipitation has also been demonstrated to be an alternative to hydroxide precipitation for removing metals from certain wastewaters. Sulfide, in the form of hydrogen sulfide, sodium sulfide, or ferrous sulfide, is added to the wastewater to precipitate metal ions as insoluble metal sulfides.

2.2.2 Biological Treatment

Biological treatment is the basic process for treating oxygen-demanding compounds, usually measured as biochemical oxygen demand (BOD), chemical oxygen demand (COD) and total organic carbon (TOC). There are a number of variations of which the most common are described below.

Oxidation Ponds - The oxidation pond is practical where land is plentiful and cheap. An oxidation pond has a large surface area and a shallow depth, usually not exceeding two meters. These ponds have long detention periods of 11-110 days. This process is not reliable in very cold climates (Barnes, 1984).

Aerated Lagoons - The aerated lagoon is a smaller, deeper oxidation pond equipped with mechanical aerators or diffused air units. The addition of oxygen enables the aerated lagoon to have a higher concentration of microbes than the oxidation pond. Where effluent standards are stringent, final clarification is necessary. However, since the effectiveness of conventional clarification on such effluents is often poor, filtration may be necessary to satisfy suspended solids limitations.

Trickling Filters - A trickling filter is an aerobic biological process. It differs from other processes in that the biomass is attached to the bed medium, which may be rock, slag or plastic. When the biomass reaches a certain thickness, part of it sloughs off. When the filter is used as the major treatment process, a clarifier is used to remove the sloughed biomass.

Rotating Biological Contactors (RBCs) - RBCs are analogous to trickling filters, in that they are fixed-film reactors. Bacterial slime grows on plastic discs rotating through the wastewater. Approximately half of the circular disc is out of the water at any one time, being aerated, and half is under water supporting biological growth.

Activated Sludge - Activated sludge is an aerobic biological treatment process in which newly grown and recycled microbial biomass are suspended uniformly throughout a holding tank to which raw wastewaters are added. Oxygen is introduced by mechanical aerators, diffused air systems or a combination of the two. The organic materials in the waste are removed from the aqueous phase by the microbial biomass and stabilized by biochemical synthesis and oxidation reactions. The basic activated sludge process consists of an aeration tank followed by a sedimentation tank or clarifier.

2.2.3 Effluent Polishing

The function of effluent polishing is to remove residual suspended solids (biological floc) which may be carried over from the secondary clarifiers. The biological floc will add BOD and certain toxic organic compounds (which are adsorbed onto or absorbed into the floc) to the final effluent, and must be removed.

Most end-of-pipe treatment systems at petroleum refineries include effluent polishing in the form of polishing filters, polishing ponds, or both. Effluent polishing filters are often single-media (sand), however, dual-media (sand, anthracite) and multi-media filters are also used. Both gravity and pressure filtration systems are utilized in refinery applications.

Polishing ponds can be equipped with baffles and oil skimmers on overflows to remove traces of free oil which may have evaded upstream treatment systems. In the event that the final effluent does not meet discharge specifications, some refinery treatment systems allow the transfer of effluent from the polishing ponds back to preliminary treatment.

2.3 ADVANCED TREATMENT TECHNOLOGIES

Advanced wastewater treatment technologies are applied after the polishing steps discussed above. These technologies include granular activated carbon (GAC), powdered activated carbon (PAC), membrane technologies, ozone and ozone/UV, and evaporative technologies.

2.3.1 Granular Activated Carbon

Adsorption on granular activated carbon (GAC) can be used for effluent polishing following biological treatment to remove residual BOD and trace level toxic organic pollutants. In some full-scale wastewater plants, GAC has also been used in place of conventional biological treatment.

Adsorption is defined as the adhesion of dissolved molecules to the surface of solid bodies with which they are in contact. Those molecules retained in the interior of any solid are subjected to equal forces in all directions, whereas molecules on the surface are subjected to unbalanced forces. This results in an inward force which can only be satisfied if other molecules become attached to the surface. Granular activated carbon particles have two properties which make them effective and economical as adsorbents. First, they have a high surface area per unit volume which results in faster, more complete adsorption and second, they have a high hardness value which lends itself to reactivation and repeated use.

The adsorption process typically uses preliminary filtration or clarification to remove insolubles. Next, the wastewaters are placed in contact with carbon so adsorption can take place. Normally, two or more beds are used so that adsorption can continue while a depleted bed is reactivated. Reactivation is accomplished by heating the carbon to 870 to 980°C (1600 to 1800°F) to volatize and oxidize the dissolved contaminants. Oxygen in the furnace is normally controlled at less than 1 percent to effect selective oxidation of contaminants (Barnes, 1984).

2.3.2 Powdered Activated Carbon

This technology consists of the addition of powdered activated carbon (PAC) to biological treatment systems. The adsorbent quality of carbon, which has been known for many years, aids in the removal of soluble organic materials in the biological treatment unit. This treatment technique also enhances color removal, clarification and system stability, as well as BOD and COD removal. Results indicate that this type of treatment, when used as a part of the activated sludge process, is a viable alternative to granular carbon systems.

2.3.3 Membrane Technologies

Membrane technologies separate dissolved, colloidal, or fine organic and inorganic materials from liquid streams. These processes, when placed after polishing technologies can produce high quality water.

Ultrafiltration - Ultrafiltration utilizes membranes of a specified molecular size to treat wastewater. The process relies on an external pressure (i.e., pumping) to input the driving force to the wastewater as it is transported through the membranes. The size opening for the ultrafiltration membrane depends on the size of the molecules to be removed from the wastewater.

Reverse Osmosis - Reverse osmosis employs pressure to force a solvent through the membrane against the natural osmotic force. This is the same type of process as ultrafiltration except that the membranes used for reverse osmosis reject lower molecular weight solutes. This means that lower flux rates occur; there is also a need for a higher operating pressure differential across the membrane than that necessary for ultrafiltration.

2.3.4 Ozone and Ozone/UV Technologies

Oxidation technologies such as ozone and ozone/UV are very effective in reducing the concentration of phenolic and other organic compounds from industrial wastewaters. Ozone reacts with organic solutes either by direct oxidation or by indirect oxidation in which hydroxyl radicals resulting from the decomposition of ozone serve as an oxidant in a series of chain reactions. Ozone is very selective for phenol, reacting about 650 times faster than with benzene. The utilization of ozonation, in conjunction with UV radiation, can be 10 to 100 times more effective in reducing organic contamination than by using ozone alone (Beckman, 1991).

2.3.5 Evaporative Technologies

The elimination of the discharge of liquid effluents can be accomplished by evaporating the treated refinery effluent streams. Vapor compression distillation is an industrial process which concentrates dissolved solids into a slurry, and evaporates the water, which can be recovered as a deionized water source. The slurry can be dried using various means (solar, incineration, etc.) for disposal on land. This technology is very energy intensive.

Some refineries use solar evaporation, deep well disposal, or percolation ponds to eliminate the discharge of wastewater. However, solar evaporation can only be used in arid climates, and discharge to the ground can be limited by other environmental laws.

2.4 POLLUTION PREVENTION MEASURES

Pollution prevention measures, in general, reduce the amount and/or toxicity of waste. These measures may include source reduction, product substitution, recycle and reuse, and process changes. Pollution prevention can be achieved by implementing simple, effective best management practices (BMPs) or by complex and costly measures such as process changes.

Discussed under the broad category of pollution prevention are the following sections which address:

- Source control
- Cooling water systems, and
- Storm water management

are subjected to unbalanced forces. This results in an inward force which can only be satisfied if other molecules become attached to the surface. Granular activated carbon particles have two properties which make them effective and economical as adsorbents. First, they have a high surface area per unit volume which results in faster, more complete adsorption and second, they have a high hardness value which lends itself to reactivation and repeated use.

The adsorption process typically uses preliminary filtration or clarification to remove insolubles. Next, the wastewaters are placed in contact with carbon so adsorption can take place. Normally, two or more beds are used so that adsorption can continue while a depleted bed is reactivated. Reactivation is accomplished by heating the carbon to 870 to 980°C (1600 to 1800°F) to volatize and oxidize the dissolved contaminants. Oxygen in the furnace is normally controlled at less than 1 percent to effect selective oxidation of contaminants (Barnes, 1984).

2.3.2 Powdered Activated Carbon

This technology consists of the addition of powdered activated carbon (PAC) to biological treatment systems. The adsorbent quality of carbon, which has been known for many years, aids in the removal of soluble organic materials in the biological treatment unit. This treatment technique also enhances color removal, clarification and system stability, as well as BOD and COD removal. Results indicate that this type of treatment, when used as a part of the activated sludge process, is a viable alternative to granular carbon systems.

2.3.3 Membrane Technologies

Membrane technologies separate dissolved, colloidal, or fine organic and inorganic materials from liquid streams. These processes, when placed after polishing technologies can produce high quality water.

Ultrafiltration - Ultrafiltration utilizes membranes of a specified molecular size to treat wastewater. The process relies on an external pressure (i.e., pumping) to input the driving force to the wastewater as it is transported through the membranes. The size opening for the ultrafiltration membrane depends on the size of the molecules to be removed from the wastewater.

Reverse Osmosis - Reverse osmosis employs pressure to force a solvent through the membrane against the natural osmotic force. This is the same type of process as ultrafiltration except that the membranes used for reverse osmosis reject lower molecular weight solutes. This means that lower flux rates occur; there is also a need for a higher operating pressure differential across the membrane than that necessary for ultrafiltration.

2.3.4 Ozone and Ozone/UV Technologies

Oxidation technologies such as ozone and ozone/UV are very effective in reducing the concentration of phenolic and other organic compounds from industrial wastewaters. Ozone reacts with organic solutes either by direct oxidation or by indirect oxidation in which hydroxyl radicals resulting from the decomposition of ozone serve as an oxidant in a series of chain reactions. Ozone is very selective for phenol, reacting about 650 times faster than with benzene. The utilization of ozonation, in conjunction with UV radiation, can be 10 to 100 times more effective in reducing organic contamination than by using ozone alone (Beckman, 1991).

2.3.5 Evaporative Technologies

The elimination of the discharge of liquid effluents can be accomplished by evaporating the treated refinery effluent streams. Vapor compression distillation is an industrial process which concentrates dissolved solids into a slurry, and evaporates the water, which can be recovered as a deionized water source. The slurry can be dried using various means (solar, incineration, etc.) for disposal on land. This technology is very energy intensive.

Some refineries use solar evaporation, deep well disposal, or percolation ponds to eliminate the discharge of wastewater. However, solar evaporation can only be used in arid climates, and discharge to the ground can be limited by other environmental laws.

2.4 POLLUTION PREVENTION MEASURES

Pollution prevention measures, in general, reduce the amount and/or toxicity of waste. These measures may include source reduction, product substitution, recycle and reuse, and process changes. Pollution prevention can be achieved by implementing simple, effective best management practices (BMPs) or by complex and costly measures such as process changes.

Discussed under the broad category of pollution prevention are the following sections which address:

- Source control
- Cooling water systems, and
- Storm water management

2.4.1 Source Control

Source control measures to minimize wastewater generation and contamination can significantly reduce the amount of effluent and contaminant load discharged from refineries. Such measures include wastewater reduction, reuse and recycle techniques.

Along with several general measures to reduce effluent, major wastewater reduction techniques address segregation, boiler condensate recovery, and treated effluent reuse. A report entitled "Water Reuse Studies" (API, 1977) discusses the practicality (and costs) of specific wastewater reduction techniques. Another study, "Wastewater Reuse and Recycle in Petroleum Refineries" (Langer, 1983) also presents information on this topic. The Langer study investigated 15 U.S. refineries; three refineries were considered to be exemplary and the remaining 12 were candidates for further effluent reduction programs. The report identifies specific wastewater reduction techniques with their anticipated effectiveness and associated costs. A summary of the findings from these studies is presented below.

Wastewater Segregation

Segregation of refinery wastewaters is important to allow for reuse of wastewaters with little or no treatment. Additionally, segregation of severely contaminated streams provides the opportunity for pretreatment, thus reducing the effects of dilution and contamination of the overall combined process wastewater stream.

The API study recommended dividing streams into three groups, by level of contamination. The first stream is high-quality and is suitable for reuse with only minimal treatment, if any. The second stream has low total dissolved solids (TDS) and requires some treatment prior to reuse, and the final stream, which has high TDS, is not suitable for reuse and requires complete treatment before discharge.

Boiler Condensate Recovery

Boiler steam condensate recovery and reuse can also significantly reduce the amount of boiler circuit wastewater. Specific measures recommended in the study include the following:

- Increase condensate recovery by the "installation or expansion of piping systems to collect steam lost by overheating, tracing, tank heating, traps, utility and leaks"

- Reduce vent losses by the "elimination of vents at process units, turbines and steam traps"

The API report also suggests using treated wastewater for boiler feed. For additional sulfide removal, if necessary, the report recommends using chemical oxidation.

Treated Effluent Reuse

For high quality wastestreams, the wastewater may be suitable for direct reuse in cooling systems or for steam generation without treatment. Other examples of reuse (with little or no treatment) include using sour water as make-up for desalters and acid gases for the neutralization of spent caustic solutions.

In the Langer report, several uses of treated effluent were identified. These included wastewater reuse for: exchanger and barometric condenser cooling, liquefaction of coke fines for dust control, firewater, service water and wash water, pump gland cooling, and other machine cooling processes. Once through cooling water can be reused as make-up for desalters, cooling towers, or as process water.

Other General Measures

According to the Langer study, other general measures for the reduction of wastewater generation include:

- conversion of barometric condensers to surface condensers
- improved management of firewater and wash water systems including the elimination of losses from "overflowing sumps, freely running hoses, temporary exchange coolers, and underground leakage."

2.4.2 Cooling Water Systems

Historically, the primary factor considered in selecting cooling water systems was the availability of water and its associated cost. However, impacts of thermal discharges, water conservation, and the attainment of discharge limitations have also become relevant considerations. The advantages and disadvantages of different cooling systems are presented in Table 2.

Although cooling water can be completely eliminated by converting to 100% air cooling systems, this may be impractical or uneconomical for some refineries due to space availability and the orientation of the heat exchanger systems.

Once Through Cooling Water Systems

In OTCW systems, due to the use of chlorine and chlorine derivatives as additives, dechlorination using sulfide or sulfite compounds may be necessary to remove residual chlorine. In recent years, as concerns about the environmental impacts of chlorine and chlorination by-products have arisen, the use of bromine and bromine compounds for OTCW treatment has also received consideration.

Cooling Tower Systems

There are several methods to minimize cooling tower blowdown streams. According to the Langer study, cooling tower blowdown can contribute up to one-third of total refinery wastewaters. Although cooling tower systems vary from plant to plant, the following general recommendations were made in the study to reduce cooling tower blowdown:

- "Recycle cooling water from pumps, compressors, and sample boxes that use blowdown
- Replace existing oil-leaking pump gland packing with mechanical seals to permit collection and recycle of blowdown to cooling tower
- Reduce use of pump gland cooling water where presently overused or eliminate service completely
- Upgrade maintenance of existing systems to reduce leakage and sump overflow."

Of the 12 plants reviewed for improvements in the study, cycles of concentration ranged from 1.1 to 9.5, with an average of 4.

The API study also addressed cooling tower systems. This report recommends pretreating raw water to improve the quality of the influent which in turn will significantly increase the cycles of concentration in cooling towers. API also suggests all uncontrolled blowdown should be eliminated when possible.

The toxicity of the blowdown can also be reduced. Recirculating water treatment chemicals containing toxic zinc and chromate compounds can be replaced with less toxic organic compounds.

TABLE 2

ADVANTAGES AND DISADVANTAGES
OF DIFFERENT TYPES OF COOLING SYSTEMS

FACTOR	OTCW	COOLING TOWER	AIR COOLING
Noise	none	low	high
Cold weather plumes	none	potential problem	none
Water Contamination Potential from Leaks	high	moderate	none
Soil Contamination Potential from Leaks	none	none to low	moderate
Air Contamination Potential	none	moderate	moderate
Cooling Efficiency	high	high	low to moderate
Energy Required	moderate	high	high
Maintenance and Labor	low	high	low
Potential for Impact for Thermal Shock to Fish	moderate to high	none	none
Potential for Impact of Water Treatment Chemicals	moderate	moderate	none
Costs	low	high	high

2.4.3 Storm Water Management

Storm water management at petroleum refineries can have a significant bearing on the mass discharge of conventional and toxic pollutants to receiving waters. In addition to increasing wastewater volumes, storm water also often contributes high levels of total suspended solids (TSS).

Under ideal circumstances, all stormwater should be segregated into the categories identified in Table 3 and treated or discharged as indicated.

TABLE 3

PETROLEUM REFINERY STORM WATER MANAGEMENT

REFINERY AREA	STORM WATER MANAGEMENT
Immediate process areas	Collection and co-treatment with refinery process wastewaters.
Developed areas of refinery, but outside immediate process areas	Segregation, collection and diversion to storm water holding pond equipped with oil baffles and skimmers. Controlled discharge after examination and testing.
Undeveloped areas	Segregation and direct discharge.

Storm water segregation can easily be incorporated into grass-roots refineries, however, segregation at existing refineries may be difficult. Segregation measures may include sloped or curbed process unit pads, individual or discreet drain and piping systems, and holding ponds for testing and controlled releases of wastewater to treatment systems or direct discharge points.

3.0 BEST AVAILABLE TECHNOLOGY

Best available technology (BAT) was identified by reviewing wastewater treatment technologies currently used in the petroleum refining industry. Specifically, treatment technologies and regulations were researched for the following: Ontario; Canada-outside Ontario; and outside Canada, including the United States, Europe and Japan.

For the purposes of this chapter, "available" means in use at refineries, other industrial facilities or evaluated in pilot- or bench-scale tests. Therefore, this chapter presents an analysis of all possible available technologies. Further evaluations of these technologies are undertaken in chapter four, where each technology, or technology train, is assessed as to whether it is a "demonstrated technology" for use as an alternative BAT technology for the purpose of setting actual limitations for the petroleum refining sector.

3.1 CURRENT STATUS IN ONTARIO

3.1.1 Overview

The current status of wastewater treatment technology was reported in the Status of Wastewater Generation and Treatment in Ontario Petroleum Refineries (SAIC, 1991). A summary of pertinent information from this document is provided in this section.

There are seven operating petroleum refineries in the Province of Ontario. They are Esso Sarnia, Shell Sarnia, Suncor Sarnia, Nova Corunna, Petro Canada Oakville, Petro Canada Mississauga, and Esso Nanticoke. Of these, Suncor Sarnia, Petro Canada Oakville, and Esso Nanticoke are conventional refineries producing a full slate of saleable petroleum products; Esso Sarnia and Shell Sarnia are co-located with large petrochemicals complexes; Petro Canada Mississauga primarily produces lubricating oils; and, Nova Corunna is principally a petrochemicals feedstock plant.

The feedstock throughput for each refinery in 1989 is listed on the following page in Table 4:

TABLE 4

ONTARIO REFINERIES
1989 FEEDSTOCK THROUGHPUT

REFINERY	M^3 PER CALENDAR DAY	BBLS PER CALENDAR DAY
Esso Sarnia	17,976	113,069
Shell Sarnia*	10,400	65,416
Suncor Sarnia	11,076	69,668
Nova Corunna**	7,350	46,305
Petro Canada Oakville	10,605	66,705
Petro Canada Mississauga	6,653	41,847
Esso Nanticoke	18,360	115,484
TOTAL	82,420	518,494

* - Shell Sarnia feedstock for 1989 includes crude oil plus 630 M^3/day of feed to the chemical plant.

** - In addition to the conventional crude/condensates, Nova purchased 4055 M^3/day of light petroleum fractions in 1989, and all of these were thermally cracked with the exception of some lighter oils.

3.1.2 Wastewater Generation

The volume of process wastewater discharged for each refinery is represented as a ratio of wastewater to crude feedstock in Table 5. The data are based upon long term average 1989 MISA flow monitoring data and 1989 feedstock throughputs. Refinery ages are also provided.

TABLE 5

ONTARIO REFINERIES
1989 PROCESS WASTEWATER PER CRUDE FEEDSTOCK FLOW

REFINERY	FLOW RATIO (U.S. GAL/BBL)	PLANT AGE
Esso Sarnia	Refinery - 52 (Total[1] - 66)	1951[2]
Shell Sarnia	Refinery - 46 (Total[1] - 54)	1952
Suncor Sarnia	34	1953
Nova Corunna	21	1977
Petro Canada Oakville	19	1957
Petro Canada Mississauga	69	1944
Esso Nanticoke	15	1978

NOTES: 1 - Total includes chemical plant.
2 - Original plant dates from 1890.

3.1.3 Process Cooling Water

The refineries in Ontario use a variety of cooling methods including once through cooling water (OTCW), recirculating cooling water using cooling towers (CT), and fin-fan or air cooling. For each refinery an estimate of the percentage of total process heat load removed by each method is presented in Table 6.

TABLE 6

ONTARIO REFINERIES
COOLING METHODS

REFINERY	PERCENTAGE OF HEAT LOAD		
	OTCW	CT	AIR
Esso Sarnia	75	20	5
Shell Sarnia*	75	0	25
Suncor Sarnia	35	60	5
Nova Corunna	0	100	0
Petro Canada Oakville	0	50	50
Petro Canada Mississauga	22	69	9
Esso Nanticoke	0	15	85

NOTE: * The Chemical Plant uses 100% recirculated water.

Recirculating cooling towers and air cooling are used to dissipate a higher percentage of the thermal loading at the newer refineries.

3.1.4 Storm Water Management

Table 7 presents a summary of the methods used to collect and treat storm water at each Ontario refinery. Segregation of storm water generally follows the guidelines established by "Petroleum Refinery Effluent Regulations and Guidelines" in 1974. These regulations classify storm water into two categories. First, storm water which falls on areas where contamination might occur such as process areas, tank farms, pipe runs, roads, roofs, parking areas, etc., must be controlled separately. Provided the water flow has been measured, a separate discharge allowance for storm water may be requested. Secondly, water falling on undeveloped areas where there is no likelihood of contamination requires no treatment. Such areas must be diked and approval from the Ministry is required to exempt these areas from collection and treatment requirements.

The MISA monitoring data for 1989 demonstrated that storm water discharged to receiving waters after ponding and testing did not contribute significantly to the mass loadings of most pollutants. Total suspended solids discharges from storm waters were significant when compared to process wastewaters. In addition, groundwater infiltration into storm sewers at older refineries can result in significant flows even during dry weather conditions.

TABLE 7

ONTARIO REFINERIES
STORM WATER MANAGEMENT

Plant	Developed Acres	Undeveloped Acres	Biological Treatment		Comments
			Treat all storm water	Possible to treat all storm water	
Esso Sarnia	145	300	YES*	---	Storm water is stored in tankage and treated in BIOX at a controlled rate.
Shell Sarnia	481	85	NO	YES**	Storm water is ponded, tested and either BIOX treated or released.
Suncor Sarnia	289	54	YES*	---	Storm water is ponded and then BIOX treated under controlled flow.
Nova Corunna	300	700	NO	YES**	Storm water is ponded, tested and either released or BIOX treated. If volume is too high 4 carbon beds in series provide treatment before release.
Petro Canada Oakville	260	37	NO	NO	Storm water is treated in BIOX to the extent possible. Storm water that does not go to BIOX goes to a surge lagoon and is tested before release.
Petro Canada Mississauga	345	66	YES*	---	Ponded and sent under controlled flow to BIOX.
Esso Nanticoke	450	1022	NO	YES	Storm water falling on process unit pads is BIOX treated. Other storm water is ponded, tested and released or it may be BIOX treated too.

STORM WATER - Run-off from developed areas of refinery.

* Includes run-off from process areas.

** Includes run-off from process areas which goes directly to process sewer.

3.1.5 Wastewater Treatment Systems

The process wastewater treatment methods in all seven refineries are similar. Biological treatment (activated sludge) is the main method to reduce organic loadings for each refinery.

The in-plant treatment practices used in Ontario refineries are often similar. Sour water strippers and sour water reuse in desalters are common. Spent caustic is also often reused elsewhere in the refinery to neutralize acidic wastewater streams.

Pretreating catalytic reforming wastewater is of particular concern. Six of the seven Ontario refineries have catalytic reforming operations. The Nova Corunna refinery is not equipped with a catalytic reformer and does not produce high octane gasolines. Two refineries (Esso Nanticoke and Petro Canada Mississauga) have reformers with continuous catalyst regeneration not equipped with caustic or water scrubbers for neutralizing and treating regeneration off-gases. Hence, there is no direct connection between the respective catalytic reforming operations and wastewater collection and treatment systems. For these refineries, CDDs and CDFs that may be generated during catalyst regeneration are emitted to the atmosphere. The methods used to treat off-gases in the four other refineries are shown in Table 8.

TABLE 8

METHODS USED BY ONTARIO REFINERIES TO TREAT GASES FROM A CATALYTIC REFORMER DURING THE REGENERATION CYCLE

Plant	No. of Reactors Regenerated in 1989	Method of Treating Recirculated Gases	Method of Treating Discharged off Gases	Dioxin (2,3,7,8 TCDD) Concentration
Esso Sarnia	16	Reformer #1. Direct contact with wash water to treatment plant. Reformer #2. Air cooled condensate to treatment plant.	Alumina drier carbon	#1. regeneration water 0.203 ppt #2. 0.234 ppt in condensate
Shell Sarnia	300	Tower with 15° Be caustic on bottom and water wash on top. Water and caustic carbon treated before treatment plant.	None	Not detected in process effluent
Suncor Sarnia	3	Caustic scrubbing. Activated carbon filtration then to treatment plant.	None	Not detected in process effluent
Petro Oakville	6	Caustic scrubbing 15°Be then to treatment system.	None	Not detected in process effluent

NOTE:

Nova Petrochemicals does not have a Catalytic Reformer

Esso Nanticoke and Petro Canada Mississauga use continuous regeneration of catalyst without scrubbing of the flue gases which go to the atmosphere.

The end-of-pipe process wastewater treatment facilities for each of the refineries are summarized below:

Esso Sarnia:	API separators, dual-media filtration, biological treatment, clarification.
Shell Sarnia:	API separators, DAF, equalization biological treatment, clarification.
Suncor Sarnia:	API separators, VTC (vertical tube coalescers), equalization, IAF, biological treatment, holding pond.
Nova Corunna:	TPI (tilted plate interceptor), holding pond, DAF, biological treatment, clarification, granular carbon (optional), holding pond.
Petro Canada Oakville:	API separators, mixed equalization, IAF, biological treatment, clarification, aerated polishing pond, mixed-media filters, holding pond.
Petro Canada Mississauga:	API separators, mixed-media filters, equalization, biological treatment, clarification.
Esso Nanticoke:	API separators, equalization, DAF, biological treatment, clarification, mixed-media filters, polishing pond.

All of the plants employ some type of post API separator treatment such as DAF (dissolved air flotation), IAF (induced air flotation), or mixed-media filtration (sand and anthracite). All of these treatment systems are roughly capable of producing the same removal of oil and suspended solids from the API separator effluent. Both DAF and IAF have the added advantage of air stripping gases either entrained or dissolved in the wastewater. In the case of Petro Canada Oakville, these stripped gases are contacted in a caustic scrubber to reduce odor emissions.

It is worth noting that Suncor, Nova Petrochemicals, Petro Canada Oakville, and Esso Nanticoke have holding ponds before discharge of the wastewater to the receiving water. These ponds are effective in further removing trace levels of contaminants and may be considered part of a tertiary treatment system.

3.1.6 Wastewater Management Practices

In all seven Ontario refineries, wastewater handling and treatment is considered an integral part of refinery operations. Many wastewater reduction or source control techniques are commonly practiced in some or all refineries. They include the following:

- Closed cycle systems for pump and compressor gland cooling water;
- Reuse of stripped sour water for desalters;
- Reuse of steam condensate from reboilers, steam traps, etc.; and
- Increased cycles of concentration in cooling tower systems.

Chemical substitution is also practiced to reduce the toxicity of the wastewater. Zinc chromate treatment chemicals have been replaced by organophosphates in cooling tower systems in some refineries.

3.1.7 Performance Summary

Table 9 shows how the refineries compare with OEQO during 1989, the year of monitoring. All numbers, except as noted, are annual average concentrations for December 1, 1988 to November 30, 1989 (preliminary reports from MISA monitoring).

Comparison with Ontario objectives shows that compliance on the average was generally good in 1989 with exception of total suspended solids which were a problem for 4 of the 7 plants. Petro Canada Oakville also had a problem with zinc and phenolics.

All of the plants passed the fish toxicity test except Petro Canada Oakville which failed 3 of 12 samples due probably to high zinc concentrations in combination with chromium.

The performance of Ontario refineries can also be compared to U.S. standards where regulated pollutant limits are based on each refinery's type, size, complexity, feed charge, and calculated target wastewater generated per crude feed charge ratios. (A more detailed description of the U.S. EPA regulations for refineries is provided later in Section 3.3.1). Presented in Tables 10 and 11 are comparisons of each Ontario refinery's performance to U.S. standards in terms of wastewater generation ratios and pollutant mass loads.

Compared to the U.S. regulations, Esso Nanticoke met all BAT limits both on a daily maximum and a 30-day average basis. The other refineries show varying degrees of compliance with the 30-day monthly average limits. It should be noted that no data are available for BOD or for hexavalant chromium. The single largest area of non-compliance is total suspended solids with 6 of the 7 refineries not meeting the U.S. limits on a continuing basis.

TABLE 9

ONTARIO REFINERIES
ANNUAL CONCENTRATION SUMMARY
(FOR THE PERIOD NOV. 30 1988 TO DEC. 1 1989)

PARAMETER	ONTARIO OBJECT'S	Esso Sarnia	P.C. Miss.	P.C. Oak.	Nova Corunna	Shell Sarnia	Suncor Sarnia	Esso Nant.
COD mg/L	200	34.750	44.083	103.833	60.917	49.833	20.667	30.583
Chromium total ug/L	1000	.000	125.950	88.548	244.317	17.952	.000	1.583
Copper ug/L	1000	1.167	3.391	.667	6.083	4.167	15.000	2.917
Lead ug/L	1000	3.333	23.091	2.000	.000	.000	.000	.433
Nickel ug/L	1000	4.167	7.509	6.183	2.417	.833	1.667	1.167
Oil & Grease mg/L	10	.415	4.479	2.451	1.718	3.377	1.190	1.582
Phenolics (4AAP) ug/L	20	3.166	8.752	42.362	5.803	6.454	6.871	3.866
Total Suspended Solids mg/L	15	13.039	26.154	22.337	16.750	64.657	7.316	6.915
Zinc ug/L	1000	17.335	91.226	402.032	437.211	32.969	51.667	27.000

TABLE 10

ONTARIO REFINERIES
PROCESS WASTEWATER FLOW RATIOS
(EPA BPT/BAT Flows versus MISA Actual Flows)

Refinery	EPA Complexity Category	Flow, U.S. gal/bbl			Flow Ratio	
		MISA Actual	EPA BPT	EPA BAT	MISA/ BPT	MISA/ BAT
Esso Sarnia	D	66	72	46	0.92	1.43
Shell Sarnia	C	54	27	24	2.00	2.25
Suncor Sarnia	C	34	32	33	1.06	1.03
Nova Corunna	C	21	32	29	0.69	0.74
Petro Canada Oakville	B	19	28	21	0.68	0.90
Petro Canada Mississauga	D	69	58	44	1.19	1.57
Esso Nanticoke	B	15	31	24	0.48	0.63

TABLE 11
COMPARISON OF PERFORMANCE OF ONTARIO REFINERIES WITH U.S. EPA PETROLEUM REFINING EFFLUENT GUIDELINES AND STANDARDS

Daily Maximum Limits and Number of Excesses**

EPA Effluent Guideline Regulated Pollutant*	Esso Sarnia		Petro Canada Mississauga		Petro Canada Oakville		Nova Petrochemical		Shell Canada		Suncor Sarnia		Esso Nanticoke	
	No. of Exceed	Limit kg/day	No. of Exceed	Limit kg/day	No. of Exceed	Limit kg/day	No. of Exceed	Limit kg/day	No. of Exceed	Limit kg/day	No. of Exceed	Limit kg/day	No. of Exceed	Limit kg/day
Ammonia plus Ammonium	0	485.01	9	187.48	0	183.43	0	189.52	0	189.35	0	314.43	0	426.81
COD	0	7,421.41	0	2,868.83	0	2,056.75	0	1,645.12	0	1,698.43	0	2,820.25	0	4,785.50
Chromium	0	9.82	2	4.23	0	3.17	4	3.03	0	3.37	0	5.45	0	6.45
Oil and grease	0	333.11	7	128.75	1	83.39	1	86.71	25	89.51	0	148.62	0	194.01
Phenolics (4AAP)	0	12.07	0	5.19	0	3.88	0	3.71	0	4.12	0	6.69	0	7.90
Sulphide	2	6.90	17	2.67	9	1.79	46	1.68	2	1.79	0	2.97	0	4.21
Ttl. suspended solids	5	730.46	84	282.36	11	191.78	12	184.57	294	190.50	1	316.32	0	446.22

30 Day Average Limits and Number of Excesses**

EPA Effluent Guideline Regulated Pollutant*	Esso Sarnia		Petro Canada Mississauga		Petro Canada Oakville		Nova Petrochemical		Shell Canada		Suncor Sarnia		Esso Nanticoke	
	No. of Exceed	Limit kg/day	No. of Exceed	Limit kg/day	No. of Exceed	Limit kg/day	No. of Exceed	Limit kg/day	No. of Exceed	Limit kg/day	No. of Exceed	Limit kg/day	No. of Exceed	Limit kg/day
Ammonia plus Ammonium	0	222.07	3	85.85	0	83.39	0	84.39	0	87.22	0	144.83	0	194.01
COD	0	3,856.80	0	1,490.88	0	1,067.29	0	853.81	1	881.35	0	1,463.46	0	2,483.29
Chromium	0	3.41	4	1.47	0	1.11	9	1.05	0	1.17	0	1.90	0	2.25
Oil and grease	0	175.33	3	67.77	0	44.46	0	46.72	3	48.20	0	80.04	0	103.47
Phenolics (4AAP)	0	2.93	0	1.26	0	.93	0	.90	0	1.00	0	1.62	0	1.91
Sulphide	1	3.09	5	1.20	5	.82	9	.84	0	.80	0	1.32	0	1.89
Ttl. suspended solids	1	467.51	7	180.72	3	122.30	5	116.80	12	120.50	0	200.10	0	284.54
EPA Subcategory	D		D		B		C		C		C		B	
1989 Calendar Day Crude Rate (1,000 bbls/day)	113.2		41.9		66.8		46.3		61.6		78.8		115.7	

* Seven of nine pollutants regulated under 40 CFR Part 419, Petroleum Refining Point Source Category.

** Limits for each facility based on 40 CFR Part 419 and information provided in Joint Technical Committee Questionnaire.

*** Excesses determined by comparing monitoring data provided for Petroleum Refining Sector to derived limits.

**** Limits for chromium and phenolics (4AAP) are based upon BAT flow.

3.1.8 Best Refinery Performance in Ontario

Based on performance, the refinery considered to be the best in Ontario is Esso Nanticoke. This refinery is the newest in Ontario and was constructed in 1978 as a new source refinery with state-of-the-art engineering for wastewater minimization, wastewater pretreatment, end-of-pipe wastewater treatment, non-contact cooling water minimization, and storm water management. Accordingly, the discharge of total effluent is the lowest of the Ontario refineries in terms of volume per unit of throughput as compared to U.S. BAT standards. Nanticoke is also among the lowest in terms of mass discharge of pollutants.

3.2 CURRENT STATUS IN CANADA, OUTSIDE ONTARIO

3.2.1 Regulations

The federal and provincial regulations governing refineries in Canada are discussed in the sections below.

Federal Legislation

Sections 33 and 34 of the Federal Fisheries Act prohibit the deposition of "deleterious substances" into any waters in Canada frequented by fish. Under these sections of the Act, Environment Canada, in consultation with the petroleum industry, issued "Petroleum Refinery Effluent Regulations and Guidelines" in January, 1974. The regulations, which apply to all new refineries that started up on or after November 1, 1973, are enforced by law. The guidelines are less stringent and are not enforced, but are statements of practice to maintain the "spirit of the law" for refineries built prior to November, 1973. In refineries where crude capacity has been added (exceeding 115%) or crude towers replaced, that portion of the refinery is subject to the regulations.

The regulations and guidelines were based upon the best practicable technology (BPT) then in use. They were intended to ensure a minimum standard of performance across the country and to eliminate "pollution havens". Even though the guidelines are not legally enforceable the industry generally responded by upgrading existing facilities to bring them into limits recommended by the guidelines.

The allowable discharges for deposit of substances are based upon crude throughput and are generally expressed in contaminant kilograms per 1000 barrel/day of crude. Table 12 presents the maximum daily Federal guidelines and regulations for maximum allowable deposits of substances. The monthly amount is not to be exceeded over the average of any month's effluent discharge, and the maximum daily should not be exceeded on any day. Also specified in the regulations and guidelines are one-day amounts which can be exceeded only one day per month.

Loadings are calculated for the following parameters: oil and grease, phenols, total suspended matter, sulphides, ammonia nitrogen, pH and acute toxicity to Rainbow Trout. The tests are done three times per week (Monday, Wednesday and Friday) and reported monthly to the Provincial Ministry. The toxicity test is done once per month. Loadings are calculated using the concept of a reference crude rate which can be altered on application to the Ministry.

Additional allowances are authorized when stormwater run-off from contaminated areas within the refinery is discharged. The allowances are expressed in kg/1000 L/day of stormwater and are presented in Table 13. Over time all plants will move to the more stringent regulations for new capacity as guidelines are replaced by regulations. Most plants currently operate on a mix of regulations and less stringent guidelines.

TABLE 12

CANADIAN FEDERAL REGULATIONS AND GUIDELINES MAXIMUM ALLOWABLE DEPOSITS OF SUBSTANCES

SUBSTANCE	MONTHLY AMOUNT kg/1000m^3/day		MAXIMUM DAILY AMOUNT kg/1000m^3/day	
	GUIDELINES	REGULATIONS	GUIDELINES	REGULATIONS
OIL & GREASE	17.1	8.6	42.8	21.4
TOTAL SUSPENDED MATTER	41.1	20.5	85.6	42.8
PHENOLS	1.7	0.9	4.3	2.1
SULPHIDE	0.6	0.3	2.9	1.4
AMMONIA NITROGEN	14.3	10.3	28.5	20.5
pH			6.0 TO 9.5	
TOXICITY			NOT MORE THAN 50% FISH MORTALITY (24 HR STATIC BIOASSAY TEST, ONCE PER MONTH)	

SOURCE: Environmental Status Report for the Canadian Petroleum Refining Industry, 1987. EPS 1/PN/3, Environment Canada, Ottawa, Ontario, 1990, p.9.

TABLE 13

CANADIAN FEDERAL REGULATIONS AND GUIDELINES ADDITIONAL ALLOWANCE FOR STORMWATER

SUBSTANCE	ALLOWANCE kg/10,000L/day of storm water
OIL & GREASE	0.10
PHENOLS	0.01
TOTAL SUSPENDED MATTER	0.30

SOURCE: Environmental Status Report for the Canadian Petroleum Refining Industry, 1987. EPS 1/PN/3, Environment Canada, Ottawa, Ontario, 1990, p.11.

Provincial Legislation

In addition to the basic requirements of the federal legislation, Ontario, Quebec, Alberta and British Columbia have adopted further requirements.

Ontario - Ontario Effluent Quality Objectives (1977) are expressed as concentrations and are provided for reference in Table 14.

Quebec - In Quebec, refineries are regulated by the Environment Quality Act - Petroleum Refineries Liquid Effluents, November 9, 1977. The limits are similar to the federal regulations (Table 12) with the exceptions that stormwater regulations apply to new as well as existing refineries, and there are no fish toxicity limitations (EC, 1990).

Alberta - Refineries in Alberta are required to meet the federal regulations as a minimum. In addition, refineries discharging effluent in "sensitive watercourses" can be subject to further standards (EC, 1990). Discharges of specific toxic elements are also regulated and are presented in Table 15.

British Columbia - In British Columbia, refineries follow recommended guidelines from the "Report on Pollution Control Objectives for the Chemical and Petroleum Industries of British Columbia", March, 1974. There are three levels for compliance. In general, Level A objectives are for new and proposed refineries. Level B objectives are to be met by all refineries over a specified time period, and Level C objectives must be met immediately. Limits also are based on the point of discharge, either marine water or freshwater. Presented in Table 16 are the Level A objectives (EC, 1990).

3.2.2 Comparison of Ontario Refineries to Canadian Refineries

A survey of 22 refineries (see Table 17) outside of Ontario was conducted to determine the level of wastewater treatment technology and performance, and to compare that which exists in the Ontario refineries.

Recently, Environment Canada surveyed all the refineries in Canada and published Report EPS1/PN/3 "Environmental Status Report for the Canadian Petroleum Refining Industry 1987" (EC, 1990). This report compared performance of the wastewater treatment systems for each plant with the limits set forth in Environment Canada's "Federal Regulations and Guidelines for Petroleum Refineries" issued in 1974.

TABLE 14

ONTARIO EFFLUENT QUALITY OBJECTIVES FOR PETROLEUM REFINERIES

SUBSTANCE	MONTHLY AVERAGE CONCENTRATION mg/L
	10
Oil and Grease	0.020
Phenols	15
Suspended Solids	10
Ammonia Nitrogen	200
Chemical Oxygen Demand	1
Chromium	1
Copper	1
Nickel	1
Lead	1
Zinc	5.5 - 9.5
pH	No more than 50% fish mortality for process effluent, once
Toxicity	through cooling water, and treated stormwater

Source: Environmental Status Report for the Canadian Petroleum Refining Industry, 1987.
EPS 1/PN/3, Environment Canada, Ottawa, Ontario, 1990, p. 13.

TABLE 15

PROVINCE OF ALBERTA EFFLUENT OBJECTIVES

SUBSTANCE	NET CONCENTRATION (mg/L)*
Chromium (hexavalent)	0.30
Cyanide	0.025
Lead	0.10
Mercury	0.0005
Zinc	1.0
Nickel	1.0

NOTE:

* The net concentration value is calculated as:

Net Concentration Value = CF/a

where: C = the net concentration measured in effluent (mg/L)
F = the effluent flow rate (gal/min per 1000 bbls of crude/day)
a = a constant, which defines nominal liquid effluent flow rates per 1000 barrels of crude processed per day as, 13.4 gal/min for refineries with disposal wells, or 20 gal/min for refineries without disposal wells.

Source: Environmental Status Report for the Canadian Petroleum Refining Industry, 1987.
EPS 1/PN/3, Environment Canada, Ottawa, Ontario, p. 13.

TABLE 16
EFFLUENT QUALITY OBJECTIVES FOR PETROLEUM REFINERIES IN BRITISH COLUMBIA(a)

SUBSTANCE	DISCHARGES TO MARINE WATER LEVEL A	DISCHARGES TO FRESHWATER LEVEL A
Oil, nonvolatile, lb/10^3 bbl. crude	---	---
Oil, total, lb/10^3 bbl. crude	1.15 (b)	0.58 (b)
BOD, 5-day, 20°C, lb/10^3 bbl. crude	2.30 (b)	2.30 (b)
Phenols, lb/10^3 bbl. crude	0.023	0.023
Sulphides and Mercaptans as S, lb/10^3 bbl. crude	0.011	0.011
Ammonia, lb/10^3 bbl. crude	0.576	0.576
Suspended solids, mg/L (c)	20.0	20.0
Settleable solids, mg/L	< 0.5	< 0.5
Floatable solids	(d)	(d)
Total solids, g/L	3.0 (e)	1.5
Cyanide, mg/L	0.10	0.1
Chromium, total, mg/L	0.2	0.2
Lead, total, mg/L	0.2	0.2
Zinc, total, mg/L	0.2	0.2
Copper, total, mg/L	0.1	0.1
Nickel, total, mg/L	0.2	0.2
Phosphate (as P), mg/L	3.0	1.0
Dissolved oxygen, mg/L	> 1.0	5.0
pH	6.5 to 8.5	6.5 to 8.5
Temperature, °F maximum	90	90
Turbidity, J.T.U.	15	10
Toxicity (f)	75	100
Process effluent volume (g) [(Imp. gal/min.)/(/10^3 bbl./day)	8.0	8.0

(a) These objectives include process effluent and storm run-off from the processing area. Excluded are ballast water from ships, once-through cooling water used for indirect cooling, and storm run-off from dyked tank storage areas and undeveloped areas.

(b) These values are tentative and subject to review.

(c) Not applicable to discharges to exfiltration ponds.

(d) Negligible.

(e) Depends upon the nature of solids other than normal marine composition.

(f) 96-h TLm Static bioassay on salmonoid species, expressed as percent by volume of effluent in receiving water which is required to give 50% survival over 96 hours.

(g) Normal dry weather flow (does not include storm runoff). Not a restrictive objective. If effluent volume discharged is greater, concentration must be reduced proportionately.

SOURCE: Environmental Status Report for the Canadian Petroleum Refining Industry, 1987. EPS 1/PN/3, Environment Canada, Ottawa, Ontario, 1990, p.14.

TABLE 17

SUMMARY OF CANADIAN REFINERIES OUTSIDE ONTARIO IN 1987 WASTEWATER TREATMENT

PROVINCE	COMPANY	LOCATION	$\frac{M^3 X 10^3}{DAY}$	PROCESS COMPLEXITY	WASTEWATER TREATMENT	% COMPLIANCE 1987	DISCHARGE
Newfoundland	Newfoundland Energy Lt.	Come by chance	11.9	High	API Separator - Act. Sludge	70%	Placentia Bay (Ocean)
Nova Scotia	Esso Petroleum	Dartmouth	11.6	High	API Separator - Act. Sludge	95%	Halifax Harbour (Ocean)
	Texaco Canada (now Esso)	Dartmouth	3.4	Moderate	API Separator - Act. Sludge	100%	Halifax Harbour (Ocean)
New Brunswick	Irving Oil	St. John	18.8	High	API Separator - Act. Sludge	100%	Bay of Fundy (Ocean)
Quebec	Ultramar	St. Romuald	14.4	High	API Separator - Aerated Lagoons	97%	St. Lawrence River
	Shell Canada	Montreal	17.5	High	API Separator - DAF-Act. Sludge	83%	St. Lawrence River
	Petro Canada	Montreal	12.0	High	API Separator - Bio Filters - Polishing Pond	93%	St. Lawrence River
British Columbia	Esso Petroleum	Loco	6.7	Moderate	API Separator - Act. Sludge	100%	Burrard Inlet (Ocean)
	Petro Canada	Port Moody	5.4	Moderate	API Separator - Non Aerated Lagoon	N/A	Municipal Sewer Storm-Burrard Inlet
	Chevron	Burnaby	5.9	Moderate	API Separator - D.A.F.	N/A	Municipal Sewer Storm-Burrard Inlet
	Shell Canada	Burnaby	2.25	Moderate	API Separator - DAF	N/A	Municipal Sewer Storm-Burrard Inlet
	Petro Canada	Taylor	2.0	Moderate	API Separator - Act. Sludge	100%	Peace River
	Husky Oil	Prince George	1.4	Moderate	API Separator - Aerated Lagoon	N/A	Local Pulp Mill for Further Bio-Treatment
Alberta	Shell Canada	Scotford	9.95	Moderate	Deep Well	N/A	Periodically to North Saskatchewan River
	Esso Petroleum	Edmonton	20.9	High	API Separator - Aerated Lagoon - Deep Well (some)	100%	North Saskatchewan River
	Petro Canada	Edmonton	15.1	High	Primary Pond - Retention Pond - Deep Well (some)	100%	North Saskatchewan River

TABLE 17, CONTINUED

SUMMARY OF CANADIAN REFINERIES OUTSIDE ONTARIO IN 1987
WASTEWATER TREATMENT

PROVINCE	COMPANY	LOCATION	$\frac{M^3 X 10^3}{DAY}$	PROCESS COMPLEXITY	WASTEWATER TREATMENT	% COMPLIANCE 1987	DISCHARGE
Alberta, cont.	Shell Canada	Bowden	.95	Low	API Separator	100%	To Ditch Normally Zero. Red Deer River
	Husky Oil	Lloydminster	3.4	Low	Deep Well	N/A	Stormwater to North Saskatchewan River
	Turbo	Balzac	3.9	High	API Separator - Deep Well	N/A	Only Stormwater to MacDonald Lake
Saskatchewan	Petro Canada	Moose Jaw	1.6	Low	API Separator	N/A	Municipal Treatment
	Co-op	Regina	6.4	Moderate	API Separator	N/A	Municipal Treatment
N.W.T.	Esso Petroleum	Norman Wells	0.6	Low	API Separator	77%	Mackenzie River

N/A - Not Applicable
% Monthly Compliance - compliance with monthly limits set by Federal Regulations and Guidelines for Petroleum Refineries 1974. Above provincial limit.
$M^3 \times 10^3$/day - Reference crude rate as established by above regulations.

Source: Environmental Status Report for the Canadian Petroleum Refining Industry, 1987.
EPS 1/PN/3, Environment Canada, Ottawa, Ontario, 1990, p. 16.

In selecting plants which might be considered for comparative purposes the following criteria were used:

(a) Only plants larger than the smallest of the Ontario refineries (Petro Canada Mississauga) at 8.3 M^3 x 10^3/day would be considered.

(b) The water treatment technology had to be similar to that used by Ontario refineries.

(c) Plants with deep well disposal and discharges to municipal treatment systems were ruled out.

(d) Plants discharging to the ocean were ruled out.

Elimination of refineries which did not fit the above criteria narrowed the choice to two plants, namely, Shell Canada Montreal and Ultramar St. Romuald Quebec. The latter plant employs a simple type of aerated lagoon without recycled sludge. This system is not comparable to the more or less return activated sludge treatment systems used throughout Ontario. Therefore this refinery was ruled out leaving Shell Montreal for further consideration.

Shell Canada Montreal-Quebec

This is one of the largest refineries in Canada and discharges its wastewater into the St. Lawrence River. The wastewater treatment system consists of API separators, DAF, activated sludge (spargers), circular clarifiers, a sludge thickener and a gravity belt filter for production of a sludge cake. The latter goes to landfill.

The following comparison between the performance of Shell Montreal and the average values obtained at the 7 Ontario refineries is presented below for the year 1987.

	SHELL MONTREAL (mg/l)	AVERAGE OF SEVEN ONTARIO REFINERIES (mg/l)
OIL AND GREASE	10.94	2.6
TOTAL SUSPENDED SOLIDS	50.16	9.8
PHENOL	0.18	0.012
SULPHIDES	0.12	0.07
AMMONIA NITROGEN	3.74	1.93
ACUTE TOXICITY	NIL	NIL

It is evident from the above comparison that the average performance of the seven Ontario refineries (December 1988 to November 1990) was markedly superior to that of Shell Montreal (December 1987). The performance requirements in Ontario tend to be more stringent than those in Quebec. Quebec generally follows the Federal Regulations and Guidelines for Petroleum Refineries whereas Ontario imposes a concentration limit as well. The net result is more demanding requirements on

Ontario. No other explanation is available since the technology used by Shell Canada is basically the same as that used throughout Ontario.

One may conclude therefore that there are no refineries in Canada outside of Ontario with comparable size, complexity, wastewater treatment technology and discharge receptors that perform as well or better than the refineries in Ontario.

3.3 CURRENT STATUS OUTSIDE CANADA

Research on the status of wastewater handling and treatment outside of Canada has been conducted with efforts concentrating on technology in USA, Europe, and Japan. Results are presented in the sections below.

3.3.1 USA

Summary of U.S. Federal Petroleum Regulations

While there were pre-existing laws, the current U.S. sector-specific regulations can trace their beginnings to the passage of the Federal Water Pollution Control Act Amendments of 1972. These Amendments changed the emphasis of U.S. water protection from water quality standards to a uniform system of technology-based standards for industrial sources.

One of the major provisions of the 1972 Amendments was the establishment of the National Pollutant Discharge Elimination System (NPDES). This created the current permit requirements for industries directly discharging into the waters of the United States. The U.S. petroleum industry was one of the major industries targeted as requiring national, technology-based effluent limitations guidelines and standards.

In 1974, the U.S. EPA promulgated Best Practicable Control Technology Currently Available (BPT) and Best Available Technology Economically Available (BAT) effluent limitations as well as New Source Performance Standards (NSPS) and Pretreatment Standards for New Sources (PSNS) for the petroleum refining industry. These regulations were based on the information presented in the 1974 Development Document for the Petroleum Refining Industry (EPA, 1974). This document used data gathered from a number of EPA and American Petroleum Institute (API) sources to identify facilities and review the performance of wastewater treatment systems within the U.S. petroleum refining industry.

The BPT and BAT limitations, as well as NSPS, were challenged in the U.S. Court of Appeals for the Tenth Circuit. On August 11, 1976, the Court upheld both the BPT limitations and NSPS, but remanded the BAT limitations, in toto, for further consideration (NRDC vs. EPA, 1976).

To update the information needed to establish BAT effluent guidelines for the petroleum refining category, EPA sent BAT questionnaires to all refineries in the United States and its territorial possessions in 1977. The surveys were made under Section 308 of the Clean Water Act. The information obtained describes the petroleum refining industry wastewater treatment practices for the year 1976 (EPA, 1982).

Information from these surveys was combined with existing information to develop an industry profile, including number of plants, their size, geographic location, manufacturing processes, wastewater generation, treatment, and discharge methods. Information on number, size, and geographic location of refineries was later updated with 1980 data from the U.S. Department of Energy (DOE). Questionnaire data aided in the final selection of plants for other aspects of this program. Flow data from the questionnaires was used to develop a flow model for the analysis of refinery wastewater production. Another objective of the survey was to obtain information identifying the use or generation of 123 toxic pollutants and determining the availability of plant data on the effectiveness of their removal.

Information on waste characterization of petroleum refining effluent is available from four sources which are briefly described below.

The first effort in determining the potential presence of the toxics involved the identification of toxics manufactured and purchased by the industry. The 1977 survey requested such information from the industry.

The second effort was the sampling of 23 refineries and two publicly owned treatment works (POTWs) to determine the presence, absence and relative concentrations of toxic, conventional and non-conventional pollutants. The refineries were selected to be representative of the manufacturing processes, the prevalent mix of production among plants, and the current treatment technologies in the industry. The selected direct discharge refineries were meeting BPT limitations. Seventeen plants were direct dischargers (refineries that discharge effluents to U.S. waters) and six were indirect dischargers (refineries that direct effluent to POTWs).

Subsequent to the 1979 proposal, EPA conducted a 60-day sampling program at two petroleum refineries. The program involved the sampling of raw and treated effluent every other day for a period of sixty days. Pollutants analyzed included toxics, but excluded asbestos and pesticides. The objectives of this program were to: (1) determine if there is a surrogate relationship between the priority pollutants and one or more of the traditional pollutant parameters (i.e., COD, TOC); and (2) confirm the presence or absence of specific priority pollutants.

In a separate program, eight refineries were sampled by EPA regional surveillance and analysis field teams.

Three major efforts were undertaken to identify and evaluate available control and treatment technologies. These included:

- A literature search that compiled available information on the status of and advances being made by the industry relative to wastewater handling and disposal.
- A review of the responses to the 1977 EPA Petroleum Refining Industry Survey which determined the status of the industry with regard to in-plant source control and end-of-pipe treatment.
- A program to assess the toxic removal effectiveness of carbon absorption treatment on a pilot scale. Granular activated carbon was tested at six plants and powered activated carbon was tested in four of the same six refineries.

All of this data was subsequently used to generate the Development Document for the revised BAT limitations (EPA, 1982). These revised BAT limitations were also challenged in the Courts and subsequently modified to their final, and current, version.

The U.S. Environmental Protection Agency (EPA) has promulgated the petroleum industry regulations within Title 40 of the U.S. Code of Federal Regulations at Part 419 (cited as 40CFR419).

According to the 1974 Development Document, the best practicable control technology currently available (BPCTCA or BPT) is based on both in-plant and end-of-pipe technology. BPT in-plant technology is based on control practices widely used within the petroleum refining industry, and includes the following:

- Installation of sour water strippers to reduce the sulfide and ammonia concentrations entering the treatment plant.
- Elimination of once through barometric condenser water by using surface condensers or recycle systems with oily water cooling towers.
- Segregation of sewers, so that unpolluted storm run-off and once through cooling waters are not treated normally with the process and other polluted waters.
- Elimination of polluted once through cooling water, by monitoring and repair of surface condensers or by use of wet and dry recycle systems.

BPT end-of-pipe treatment technology is based on the existing wastewater treatment processes currently used in the petroleum refining industry. These consist of equalization and stormwater diversion; initial oil and solids removal (API separators or baffle plate separators); further oil and solids removal (clarifiers, dissolved air flotation, or filters); carbonaceous waste removal (activated sludge, aerated lagoons, oxidation ponds, trickling filter, activated carbon, or combinations of these); and filters (sand, dual-media, or multi-media) following biological treatment methods.

Granular media filtration or polishing ponds prior to final discharge are often needed so that the total suspended solids and oil concentrations in the final effluent can be generally maintained at approximately 10 mg/l and 5 mg/l, respectively. The final polishing step is considered BPT for the U.S. petroleum refining industry.

The EPA has determined that, for the petroleum refining industry, Best Available Control Technology Economically Achievable (BAT) is equivalent to the existing Best Practicable Technology Currently Available (BPT) level of control (EPA, 1982). However, additional flow reduction requirements for phenol and chromium are included in BAT, as well as lower attainable concentrations.

In the development of the 1974 regulations, EPA found that the industry can be divided into five discrete subcategories:

Subcategory		**Basic Refinery Operations Included**
Topping	A	Topping and catalytic reforming whether or not the facility includes any other process in addition to topping and catalytic process. This subcategory is not applicable to facilities which include thermal processes (coking, visbreaking, etc.) or catalytic cracking.
Cracking	B	Topping and cracking, whether or not the facility includes any processes in addition to topping and cracking, unless specified in one of the subcategories listed below.
Petrochemical	C	Topping, cracking and petrochemical operations, whether or not the facility includes any process in addition to topping, cracking and petrochemical operations*, except lube oil manufacturing operations.
Lube	D	Topping, cracking and lube oil manufacturing processes, whether or not the facility includes any process in addition to topping, cracking and lube oil manufacturing processes, except petrochemical operations*.
Integrated	E	Topping, cracking, lube oil manufacturing processes, and petrochemical operations, whether or not the facility includes any processes in addition to topping, cracking, lube oil manufacturing processes and petrochemical operations*.

* The term "petrochemical operations" shall mena the production of second generation petrochemicals (i.e., alcohols, ketones, cumene, styrene, etc.) or first generation petrochemical and isomerization products (i.e., BTX, olefins, cyclohexane, etc.) when 15% or more of refinery production is as first generation petrochemicals and isomerization products.

For each refinery a size and complexity factor is calculated to account for additional variations within each subcategory.

For BAT, the final ("refined") regulation is based on the following flow model:

$$FLOW = 0.0021C + 0.0127A + 0.0236K + 0.0549L + 0.0212R$$

Where:

FLOW = Net process wastewater in million gallons/day
C = Sum of crude process rates in 1000 bbl/day
A = Sum of asphalt process rates in 1000 bbl/day
K = Sum of cracking and coking process rates in 1000 bbl/day
L = Sum of lube process rates in 1000 bbl/day
R = Sum of reforming and alkylation process rates in 1000 bbl/day

Effluent Limitations Example

Effluent limitations for the petroleum refining industry are expressed as mass limitations, i.e., restrictions on the total quantity of pollutants that may be discharged. (Total mass of pollutants in an effluent stream depends on both the total effluent flow and the concentration of pollutants in that flow.)

BPT - To arrive at the BPT effluent limitations for a specific plant, 40CFR419 requires a 7-step calculation. For the calculations, the following information is necessary: the subcategory to which the refinery belongs; capacity of processes within the refinery (crude, cracking, etc.); the size and process "factors" designated for the refinery; and the unadjusted effluent limitation listed for each of the regulated pollutants on both a 1-day maximum and 30-day average. The actual limitation is then calculated by multiplying the size factor, the process factor, the unadjusted effluent limitation and the refinery throughput together to establish the amount of each pollutant allowed, in pounds (or kilograms) per day. An example of this procedure follows:

NOTE: This example is based on a subcategory D facility. Each subcategory is calculated using this same methodology, but utilizes size and process factor charts for the specific subcategory. The size and process factors (Tables 18 and 19) are found in the appropriate sections of 40CFR419.

TABLE 18

U.S. PETROLEUM REFINERY
BPT LIMITATIONS-SUBCATEGORY D
SIZE FACTOR

1,000 bbl of Feedstock Per Stream Day	SIZE FACTOR
Less than 49.9	0.71
50.0 to 74.9	0.74
75.0 to 99.9	0.81
100.0 to 124.9	0.88
125.0 to 149.9	0.97
150.0 to 174.9	1.05
175.0 to 199.9	1.14
200.0 or greater	1.19

TABLE 19

U.S. PETROLEUM REFINERY
BPT LIMITATIONS-SUBCATEGORY D
PROCESS FACTOR

PROCESS CONFIGURATION	PROCESS FACTOR
Less than 6.49	0.81
6.5 to 7.49	0.88
7.5 to 7.99	1.00
8.0 to 8.49	10.9
8.5 to 8.99	1.19
9.0 to 9.49	1.29
9.5 to 9.99	1.41
10.0 to 10.49	1.53
10.5 to 10.99	1.67
11.0 to 11.49	1.82
11.5 to 11.99	1.98
12.0 to 12.49	2.15
12.5 to 12.99	2.34
13.0 or greater	2.44

TABLE 20

U.S. PETROLEUM REFINERY
BPT LIMITATIONS-SUBCATEGORY D
PROCESS CONFIGURATIONS CALCULATION

Process	Capacity (1,000 bbl per stream day)	Capacity Relative Throughput	Weighting Factor	Processing Configuration
Crude:				
Atm...............	125.0	1.00	....	....
Vacuum..........	60.0	0.48	....	....
Desalting.......	125.0	1.00	....	....
Total.........	....	2.48	x1	= 2.48
Cracking				
FCC.............	41.0	0.326	....	....
Hydrocracking.....	20.0	0.160	....	....
Total.........	....	0.488	x6	= 2.93
Lubes.............	5.3	0.042	....	....
	4.0	0.032	....	....
	4.9	0.039	....	....
Total.........	....	0.113	x13	= 1.47
Asphalt...........	4.0	0.032	x12	= 0.38
Refinery process configuration...	....	....	....	= 7.26

EXAMPLE:

Application of the above factors for a lube refinery with 125,000 bbl per stream day throughput (subcategory D).

Steps:

1) Size Factor = 0.97 (125,000 bbl/stream day throughput)

2) Calculate Process Configuration (Table 20). Process configuration = 7.26.

3) Process Factor = 0.88 (from process factor table with process configuration = 7.26)

4) Calculate the limits for each parameter. Multiply the limit from 40CFR419 by both the size factor and the process factor.

Example: BOD_5 (max. 1 day) = 17.9 (from 40CFR419)

17.9 x 0.88 x 0.97 = 15.3 lbs/1,000 bbl crude feedstock

Therefore: BOD_5 = 15.3 lbs/1,000 bbls x 125K bbl/day = 1912.5 lbs/day

BAT - The BAT effluent limitations for phenolic compounds (4AAP), total chromium and hexavalent chromium require a slightly different calculation method which uses only the capacity of the processes within the refinery (crude, cracking, etc.) and the BAT effluent limitations factor for the specific pollutant (from 40CFR419). Each total process rate (in 1,000 bbl/day) is multiplied by the effluent limitation and summed together to arrive at the BAT limitation allowed, in pounds (or kilograms) per day, as shown below:

> Using the same 125,000 bbl/day facility that was used in the BPT limitation calculation:

TABLE 21

U.S. PETROLEUM REFINERY
EXAMPLE BAT LIMITATIONS-SUBCATEGORY D
PROCESS RATE CALCULATION

Refinery Process	Process Feedstock Rate 1,000 bbl/day	
		TOTAL
1. Atmospheric crude distillation................	125.0	
2. Crude desalting..............................	125.0	
3. Vacuum crude distillation.....................	60.0	
Total crude processes (C)....................		310.0
6. Fluid catalytic cracking......................	41.0	
10. Hydrocracking................................	20.0	
Total cracking and coking processes (K)......		61.0
18. Asphalt production...........................	4	
Total asphalt processes (A)..................		4.0
21. Hydrofining, etc.............................	5.3 4.0 4.9	
Total lube processes (L)....................		14.2
8. Catalytic reforming..........................	10	
Total reforming and alkylation processes (R).		10

[Note: For BAT limitation calculations, reforming and alkylation processes are included.]

Steps:

1) Calculate process rate (Table 21).

2) Choose pollutant, property and process type limitation factor from appropriate 40CFR419 chart (Table 22).

3) Multiply the limitation factor by the equivalent refinery process totals and sum together.

30 day avg. effluent limitation for phenolic compounds (4AAP), lb/1,000 feedstock

$$= (0.003 \times 310) + (0.036 \times 61) + (0.019 \times 4) + (0.090 \times 14.2) + (0.032 \times 10)$$

$$= 4.8 \text{ lb/day}$$

TABLE 22

U.S. PETROLEUM REFINERY
BAT LIMITATIONS FACTORS SUBCATEGORY D

Pollutant or Pollutant Property and Process Type	BAT Effluent Limitations Factor	
	Maximum for Any 1 Day	Average of Daily Values for 30 Consecutive Days Shall Not Exceed
	English units (pounds per 1,000 bbl of feedstock)	
Phenolic compounds (4AAP):		
Crude	0.013	0.003
Cracking and coking	0.147	0.036
Asphalt	0.079	0.019
Lube	0.369	0.090
Reforming and alkylation	0.132	0.032
Total chromium:		
Crude	0.011	0.004
Cracking and coking	0.119	0.041
Asphalt	0.064	0.022
Lube	0.299	0.104
Reforming and alkylation	0.107	0.037
Hexavalent chromium:		
Crude	0.0007	0.0003
Cracking and coking	0.0076	0.0034
Asphalt	0.0041	0.0019
Lube	0.0192	0.0067
Reforming and alkylation	0.0069	0.0031

U.S. Petroleum Industry

Presently, the U.S. petroleum industry consists of over 200 refineries ranging in refining capacity from 50 to 665,000 barrels per day (EPA, 1982). From this population, seven refineries have been selected for the purpose of this report. These refineries have been selected based upon demonstrated performance with respect to U.S. BAT, size range similar to the Ontario refineries, production of similar products, and wastewater treatment technologies.

The specific criteria established for selecting the best refineries in the United States are as follows:

- Those refineries that are subject to chemical-specific State water quality standards
- Those refineries that are subject to toxicity requirements, and
- Those refineries that have installed treatment beyond BAT requirements

These criteria were established because they would help identify those refineries that had installed technologies beyond those used at typical facilities.

Beyond that, U.S. EPA's subcategorization scheme relates to water usage, not effluent quality. U.S. EPA data has demonstrated that all refineries have very similar raw waste characteristics. In addition, refineries with BAT treatment systems use very similar treatment methods, no matter which subcategory. Therefore, the U.S. facilities were chosen to be similar in size to the facilities in Ontario, and to have at least cracking processes in-place. The seven best refineries that were chosen included five "B" facilities, a "D" facility and an "E" facility, by subcategory. It should be noted that a refinery in subcategory "E" also includes subcategory "C" and "D" operations. Therefore, the "E" refinery selected includes the characteristics of both "C" and "D" facilities.

The seven refineries chosen are the following:

- Pacific Refining; Hercules, CA
- Chevron USA; Richmond, CA
- Chevron USA; Salt Lake City, UT
- BP Oil; Ferndale, WA
- Ashland Petroleum; Canton, OH
- Mobil Oil; Paulsboro, NJ
- Conoco Inc.; Commerce City, CO

Table 23 presents a summary of the basis for limitations in these refineries NPDES permits. As can be seen, there are a significant number of water quality -based on toxic pollutant limitations for these facilities. A brief description of each refinery follows:

Pacific Refining - Located in Hercules, California. The facility has a stream day capacity of 57,000 bbl/day. Refinery processes include atmospheric and vacuum distillation, thermal cracking, catalytic reforming, catalytic hydrocracking, and catalytic hydrotreating. Refinery products include propane, butane, gasoline, aviation fuel, diesel fuel, fuel oil and asphalt. This facility is classified as subcategory "B".

Wastewater flow averages 0.22 MGD and consists of sanitary wastes, process wastes (0.203 MGD), cooling tower blowdown, boiler blowdown, and stormwater run-off. Wastewater treatment processes include API oil/water separation, DAF, hydrogen sulfide oxidation, ammonia stripping, activated sludge, aerated lagoon, and aerobic digestion (sanitary wastes).

Chevron/California - Located in Richmond, California. This facility has a stream day capacity of 250,000 bbl/day. Refinery processes include atmospheric and vacuum distillation, desalting, thermal cracking, fluid catalytic cracking, hydrotreating, hydrocracking, various lube processes, asphalt production and oxidation, alkylation, and catalytic reforming. The refinery products include fuels, lubricants, and petrochemicals. This refinery is classified in subcategory "E".

Wastewater flow averages 48 MGD and consists of treated process wastewater (6.9 MGD), stormwater run-off, and other wastes. Wastewater treatment processes include aerated lagoons and oxidation ponds.

TABLE 23

BEST U.S. REFINERIES
BASIS FOR NPDES PERMIT LIMITATIONS

POLLUTANT	PACIFIC (CALIF.)	CHEVRON (CALIF.)	CHEVRON (UTAH)	BP OIL (WASH.)	ASHLAND (OHIO)	MOBIL (N.J.)	CONOCO (COLO.)
BOD_5	T	T	T	T	T	W	T
COD	T	T	T	T	T	T	W
OIL&GREASE	T	W	T	T	W	W	W
CrT	T	T	T	T	T	T	T
Cr_6	T	T	T	T	T	T	T
NH_3 (N)	T	T	T	T	W	T	T
PHENOLS	T	T	T	T	T	T	T
TSS	T	T	T	T	T	T	W
SULFIDE	T	T	T	T	T	T	T
TOC	T	T	T	T	T	T	T
NICKEL	W	W	W	W	W	W	W
SELENIUM	W	W	W	W	W	W	W
VANADIUM	W	W	W	W	W	W	W
COBALT	W	W	W	W	W	W	W
CADMIUM	W	W	W	W	W	W	W
ARO.HYDROCARB.	W	W	W	W	W	W	W
COPPER	W	W	W	W	W	W	W
ARSENIC	W	W	W	W	W	W	W
ZINC	W	W	W	W	W	W	W
MERCURY	W	W	W	W	W	W	W
SILVER	W	W	W	W	W	W	W
LEAD	W	W	W	W	W	W	W
ACENAPHTHENE	W	UNK.	W	W	W	W	W
BENZENE	W	UNK.	W	W	W	W	W
BENZO(a)PYRENE	W	UNK.	W	W	W	W	W
CHLOROFORM	W	UNK.	W	W	W	W	W
CHRYSENE	W	UNK.	W	W	W	W	W
NAPHTHALENE	W	UNK.	W	W	W	W	W
PHENANTHRENE	W	UNK.	W	W	W	W	W
PYRENE	W	UNK.	W	W	W	W	W
TOLUENE	W	UNK.	W	W	W	W	W

NOTES: T - TECHNOLOGY BASED (BAT/BPT)
W - WATER QUALITY STD.

Chevron/Utah - Located in Salt Lake City, Utah. This facility has a stream day capacity of 46,000 bbl/day. Refinery processes include atmospheric and vacuum distillation, desalting, vacuum flasher, Houdry catalytic cracking, fluid catalytic cracking, delayed coker, hydrogen denitrification, catalytic reformer, and HF alkylation. The refinery produces propane, gasoline, jet fuel, diesel fuel, stove oil, and coke. The classification for this facility is subcategory "B".

Wastewater flow averages 1.41 MGD and consists of process wastewater (0.9 MGD), cooling tower blowdown, boiler blowdown, laboratory wastewater, and stormwater run-off. Wastewater treatment processes include API oil/water separator, baffle pond, an induced air flotation unit, bio disks, oxidation ponds, sand filter, and a final pond.

BP Oil - Located in Ferndale, Washington. The facility has a stream day capacity of 90,000 bbl/day. Refinery processes include atmospheric and vacuum distillation, catalytic cracking, catalytic reforming, and catalytic hydro-treating. The refinery produces gasoline, diesel fuel, and other petroleum-based products. This facility is classified as subcategory "B".

The facility discharges an average of 1.5 to 4.0 MGD of wastewater consisting of process wastes (1.558 MGD), stormwater run-off, sanitary wastes, and ballast water. The wastewater receives primary and secondary treatment in a wastewater treatment system consisting of an API oil/water separator, an induced air flotation unit, a trickling filter, an aeration basin, an activated sludge unit, a clarification pond, a dewatering basin, and a final holding pond.

Ashland Petroleum - Located in Canton, Ohio. This refinery has a stream day capacity of 68,000 bbl/day. Refinery processes include atmospheric and vacuum distillation, desalting, fluid catalytic cracking, hydrotreating, catalytic reforming, as well as asphalt production and oxidation. This facility produces gasoline, diesel fuel, jet fuel, heating oil, and asphalt. This refinery is classified in subcategory "B".

An average of 1.44 MGD of wastewater is discharged per day. This consists of process wastewater (1.0 MGD), cooling water, boiler blowdown, and stormwater run-off. These wastewaters are treated with an oil/water separator pond, a primary settling tank, DAF units, aeration tanks, and clarifier.

Mobil Oil - Located in Paulsboro, NJ. This facility has a stream day capacity of 104,000 bbl/day. Refinery processes include distillation, cracking and coking, reforming, and alkylation. A major product of this refinery is lubricants; therefore, this refinery is classified as subcategory "D".

This facility discharges an average of more than 12.72 MGD of wastewater per day, consisting of process wastewaters (12.7 MGD), cooling waters, stormwater run-off, ballast water, and fire-drill run-off. Wastewater treatment consists of a DAF unit, an activated sludge unit, trickling filter, and filtration.

Conoco, Inc. - Located in Commerce City, Colorado. This refinery has a stream day capacity of 50,000 bbl/day. Refinery processes include atmospheric and vacuum distillation, desalting, fluid catalytic cracking, and asphalt production. This facility produces gasoline, jet fuel, fuel oil, L-P gas, and asphalt. The refinery is classified in subcategory "B".

An average of 2.16 MGD of wastewater is discharged per day consisting of process wastewater (0.42 MGD), cooling tower blowdown, boiler blowdown, stormwater run-off, and other non-oily liquid wastes. The wastewater is treated using an API oil/water separator, flocculation, a biological treatment lagoon, and an aerated lagoon.

Performance of U.S. Refineries

The wastewater discharged from these U.S. refineries is considered to be one indication of their overall performance level. The calculated BPT flow amount of wastewater per barrel of feedstock (gals/bbl) is based on the complexity of the refining processes within the specific refinery. This is derived from an EPA model. The actual water usage (gal/bbl) is computed from the amount of water actually used per barrel of throughput at the specific refinery. The comparison of the actual flow to the calculated BPT flow is an indication of the performance mentioned above. As presented in Table 24, most of the selected U.S. refineries are below their calculated BPT flows.

The performance of the refineries can also be described in terms of pollutant discharge concentrations. Presented in Table 25 are the average and lowest (best) concentrations for the seven U.S. refineries.

TABLE 24

COMPARISON OF PERFORMANCE OF U.S. REFINERIES WITH U.S. EPA BPT and BAT STANDARDS - EFFLUENT FLOW PER CRUDE FEEDSTOCK (U.S. GALS/BBL)

REFINERY	EPA SUBCATEGORY	STREAM DAY CAPACITY (1,000bbl./day)	ACTUAL FLOW	BPT FLOW	BAT FLOW	BPT RATIO	BAT RATIO
PACIFIC (CA)	B	57	3.56	22.88	23.48	0.16	0.15
CHEVRON (CA)	E	250	27.64	86.96	50.10	0.32	0.55
CHEVRON (UT)	B	46	19.57	25.89	28.61	0.76	0.68
BP OIL (WA)	B	90	17.31	19.24	17.56	0.90	0.99
ASHLAND (OH)	B	68	14.71	30.94	44.16	0.48	0.33
MOBIL (NJ)	D	104	122.31	34.85	47.44	3.51	2.58
CONOCO (CO)	B	50	8.40	26.00	28.99	0.32	0.29
Average						0.92	0.80

TABLE 25

PERFORMANCE OF U.S. REFINERIES POLLUTANT DISCHARGE CONCENTRATIONS

POLLUTANT (mg/l)	AVERAGE OF 7 IN U.S.	BEST OF 7 IN U.S.
TSS	31	11
COD	85	58
O & G	4.08	1.79
NH_3 (N)	5.21	0.1
Sulfide	0.03	ND
Phenols (4AAP)	0.047	0.0038
CrT	0.028	0.010
Lead	< 0.02	< 0.005 (max)
Zinc	0.09	0.005 (max)
Benzene	< 0.005	< 0.004 (max)
Toluene	0.005 (max)	0.004 (max)
Naphthalene	< 0.003 (max)	< 0.003 (max)

3.3.2 Europe

Data Collection

To obtain information on Western European petroleum refinery wastewater treatment and discharge requirements, international organizations, national governments, industry groups, and oil companies were contacted. Specifically, the information requested from these sources included the following:

- current and proposed discharge regulations for oil refineries, in particular, limitations on toxic pollutants;
- monitoring data;
- control technologies in use or under consideration; and
- enforcement.

Data gathering focused upon three countries which account for 60 percent of the refining capacity in Western Europe; the United Kingdom; the Federal Republic of Germany (West Germany), and the Netherlands (Triennial Report, 1987).

Regulations and Standards

In European petroleum refineries, water discharge regulations are promulgated and monitored at the national, provincial, and local levels. In addition, refineries and national governments follow the recommendations of the Paris Commission and the directives of the European Commission.

The Paris Commission was established to limit land based pollution of the North Sea. The Commission designs and issues permits on a plant by plant basis and is responsible for regular environmental monitoring of 31 of the 54 refineries under it's sphere of influence (Triennial Report, 1987).

The European Commission makes environmental policies which are binding to the 12 current members of the European Community based on the mutual responsibility of all European countries for their common environment. The participating countries are Belgium, Denmark, France, Germany, Luxembourg, Ireland, Italy, Greece, The Netherlands, Portugal, Spain, and the United Kingdom.

In 1973, European Heads of State felt that economic expansion should be accompanied by an improved quality of life including environmental protection. As a result, the first environmental action program was established. The program continued to evolve until 1983 when a preventative approach to environmental protection was adopted. The European Commission issues directives to industry including petroleum refineries to assess the impacts on all aspects of the environment.

Decisions made by the European Commission must be approved by the Ministers of the European Community after a public comment period.

The European Commission also provides funding for research and demonstration projects aimed at developing clean technologies and recycling. The Netherlands, Germany, and the United Kingdom do not have national standards for toxic pollutants in petroleum refinery effluents with the exception of cadmium, mercury, and a few other substances regulated in European Commission directives. Removal of some toxics from refinery effluents does occur as controls for conventional pollutants (BOD, COD, oils, grease, etc.) can capture a significant percentage of toxic pollutants. However, controls and standards for conventional pollutants emitted by refineries vary widely in European countries. In general, discharge permits are designed and negotiated on a plant- by-plant basis. Permit considerations and discharge limits are dependent upon some combination of plant processes, treatment technology, water quality objectives, and discharge standards. Examples of regulated pollutants and typical standards for the Paris Commission, Netherlands, United Kingdom, and Germany are provided in Table 26.

Monitoring

Regular environmental monitoring occurs at 31 of 54 refineries listed by the Paris Commission (Triennial Report, 1987). Monitoring for the toxic pollutants mercury and cadmium is required by European Commission directives. Other toxic pollutants (organics and heavy metals) are monitored by government authorities in only a few countries. For example, the Netherlands national government does monitor toxic pollutants in refinery and other industrial effluent waters.

Performance and Treatment Technologies

In general, refineries continue to cut discharges of oil and other substances including toxics and to improve treatment technologies and efficiency. Both the Paris Commission and CONCAWE (the oil companies' European organization for environmental and health protection) report large percentage declines in the total amount of pollutants discharged from refineries over the past ten years based on national government and industry data.

CONCAWE surveyed 89 refineries (representing 82 percent of Western Europe's refineries) in 1987. Of these, about 75% were equipped with biological wastewater treatment systems (CONCAWE, 1989). According to the Paris Commission, in 1987, 63% of its member country refineries (38 of 60) were equipped with biological treatment, representing an increase from 49% in 1981 (Triennial Report, 1987). Fewer and fewer refineries rely solely on oil/water separation for wastewater treatment.

Future Standards

All refineries in the European Commission and Paris Commission countries are gradually adopting more stringent effluent standards. In particular, increasingly stringent national and provincial regulations are expected to include regulations for toxic pollutants. New regulations will include a combination of water quality-based standards (allowing for plant-to-plant variations), best available technology (focusing on flow reduction and biological treatment), and national or provincial discharge limits for toxics.

Summary

Based upon available information, European refinery wastewater treatment technologies are no more advanced than those found in Ontario and U.S. refineries. Toxics monitoring data is limited, however more stringent regulations for pollutants including toxics are anticipated for the future.

Table 26

EXAMPLES OF EUROPEAN STANDARDS

Paris Commission[1]	
Oil concentration	5 mg/l (ave.)
Oil concentration (ballast water)	20 mg/l (ave.)
Total oil discharged	3 g/tonne of refinery capacity (ave.)
Netherlands[2]	
Oil concentration - old refineries	30 mg/kg (ave.)
Oil concentration - new refineries	10 mg/kg (ave.)
Oil concentration - ballast water	20 mg/kg (spot sample)
Germany[3] Proposed:	
COD	120 mg/l (grab sample)
Total hydrocarbon	2 mg/l (grab sample)
Organic Cl	0.1 mg/l (grab sample)
NH_4-N	10 mg/l (grab sample)
S^{-}	0.6 mg/l (grab sample)
Phenols	0.15 mg/l (grab sample)
United Kingdom[4] Typically Controlled Pollutants:	
Oil & Grease concentration	20 mg/l (example)
Temperature	variable
Suspended Solids	variable
Copper	variable
Sulphides	variable

Sources:

[1] Paris Commission - Procedures and Decisions Manual. Feb. 1989, pp. 3-4.

[2] Broseliske, G.H., Ministry of Public Works, Institute for the Purification of Water, 1990. Correspondence. Nov. 22, 1990, p. 3.

[3] Triennial Report on Discharges from Refineries in 1987. 1989. Eleventh Meeting of the Paris Commission, Dublin, June 19-22, 1989.

[4] Bird, Dr. P., National Rivers Authority, 1990. Correspondence. Dec. 13, 1990.

3.3.3 Japan

Data Collection

To obtain information on Japanese petroleum refinery wastewater treatment and discharge requirements, organizations such as the Petroleum Association of Japan (PAJ), the Japanese Information Center, Japanese Environment Agency, the Center for Global Change and the Japanese Embassy were contacted, as well as a computerized literature search.

The information collected from these groups includes:

- current environmental laws in Japan, including emission control measures, environmental quality standards and limitations on toxic pollutants
- pollution control measures taken in refineries such as water pollution control, reducing quantity of plant wastewater and segregating wastewater treatment
- past and present financial expenditures for pollution control equipment

Japan currently has 49 petroleum refineries that, in 1982, produced petroleum products at a total crude oil distillation capacity (total topping capacity) of 5,940,000 bbl/day (IPCAJ, 1983).

Regulations and Standards

Environmental policy in Japan is administered by the Basic Law for Environmental Pollution Control which was enacted by the "Diet" on August 3, 1967.

The Basic Law establishes fundamental national principles and policies, defines the scope of pollution control, assigns responsibilities for carrying out control measures, and sets forth basic guidelines for regulations and administrative procedures.

It also establishes general principles governing the financial responsibility of the Government, local governments, and private enterprise, authorizes governments action for resolving interjurisdictional disputes and other conflicts arising from environmental pollution matters, and provides for a government role in mitigating damage caused by environmental pollution.

Under the Basic Law (Articles 3 through 6), the Government bears responsibility to establish fundamental and comprehensive policies for environmental pollution control as part of its function to protect public health and conserve natural resources. Local government bodies execute those national policies and develop measures to meet special local needs, taking into account local social and physical conditions, including setting a more stringent local standard.

To prevent pollution caused by their operations, private enterprises must institute measures such as treatment or disposal of smoke and soot, liquid effluents, and wastes, and, insofar as possible, must minimize adverse environmental effects from the used products they produce or process (IPCAJ, 1983).

Environmental Quality Standards are established for water quality and are defined in three different ways:

1. Standards relating to human health.
2. Standards relating to the living environment.
3. Standards of nitrogen and phosphorus concentrations in lakes.

The standards relating to human health are indiscriminate to all aquatic areas and limit cadmium, cyanide, organic phosphorus, lead, hexavalent chromium, arsenic, total mercury, alkyl mercury and PCB's.

The standards relating to the living environment are set up by classifying the public water areas into public use categories. These standards limit pH, BOD, COD, suspended solids, dissolved oxygen and fecal coliform. There are also standards for nitrogen and phosphorous.

Water pollution is controlled in Japan under the Water Pollution Control Law. This law stipulates effluent water quality limitations and categorizes public water areas, including rivers, lakes, harbors and coastal sea, and the water lines connected to them.

These standards for effluent water under the Water Pollution Control Law are as listed below:

STANDARDS RELATING TO HUMAN HEALTH		STANDARDS RELATING TO LIVING ENVIRONMENT	
Cadmium	0.1 mg/l	pH (effluent to coastal sea)	5.0-9.0
Cyanide	1.0 mg/l	(others)	5.8-8.6
Organic phosphorous	1.0 mg/l		
Lead	1.0 mg/l	BOD	160 mg/l
Hexavalent chromium	0.5 mg/l	COD	160 mg/l
Arsenic	0.5 mg/l	Suspended solid	200 mg/l
Total mercury	0.005 mg/l	n-Hexane extract	
Alkyl mercury	not detectable	- mineral oil	5 mg/l
PCB	0.003 mg/l	- animal/vegetable oil	30 mg/l
		Phenols	5 mg/l
		Copper	3 mg/l
		Zinc	5 mg/l
		Dissolved iron	10 mg/l
		Dissolved manganese	10 mg/l
		Chromium	2 mg/l
		Flourine	15 mg/l
		Coliform	3000 MPS/100 ml

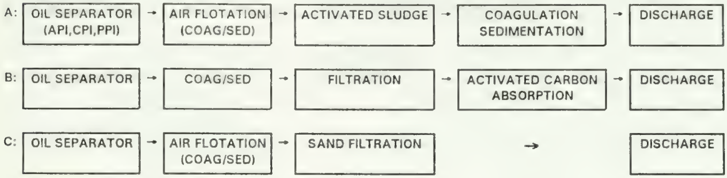
Several other laws exist that relate to water pollution, such as: Sewerage Law, River Law, Marine Pollution Control Law, Port Regulation Law, Poisonous and Deleterious Substances Control Law, Laws and regulations for waste treatment and disposal and International conventions for marine pollution control and ocean dumping.

Treatment Technologies and Performance

Japanese refineries recognize that the basic method for water pollution control is to reduce the amount of wastewater discharged. The total amount of process wastewater discharged is about 9,000 M^3/day per refinery. The quantity of wastewater has been reduced by the reuse of the water and by the employment of air fin coolers.

Attention has been given to the reuse of industrial water; a ratio of 80% has been reached, which is the highest level in Japanese industry. The air fin coolers have been introduced into almost all refineries for the purpose of reducing wastewater. In the wastewater treatment facilities, wastewater lines have been categorized by type and degree of use in order to improve efficiency and reduce the amount of total wastewater treated. In recent years, steam strippers have also been employed in order to reduce the load of wastewater.

The following three examples show the typical waste treatment processes used in refineries in Japan (IPCAJ, 1983):


A: OIL SEPARATOR (API,CPI,PPI) → AIR FLOTATION (COAG/SED) → ACTIVATED SLUDGE → COAGULATION SEDIMENTATION → DISCHARGE
B: OIL SEPARATOR → COAG/SED → FILTRATION → ACTIVATED CARBON ABSORPTION → DISCHARGE
C: OIL SEPARATOR → AIR FLOTATION (COAG/SED) → SAND FILTRATION → DISCHARGE

Past and Present Investments

Pollution control investment has gradually decreased since fiscal 1975, when the investment for pollution control equipment in the petroleum industry (based on construction costs) peaked, amounting to approximately 190 billion Yen (about 60% of the total equipment investment).

This decrease is due to the completion of the initial program, a 10% investment level for pollution control equipment has been maintained (IPCAJ, 1983).

Future Standards

In October 1990, the Central Council for Environmental Pollution Control submitted new, stricter water quality regulations. In response to these new regulations, the government set fiscal 1994 as a goal for the third emissions regulatory policies, which would, in June 1991, enact new regulations standards in each prefecture (FBIS, 1991).

Summary

The Japanese refining industry utilizes source control as an integral part of pollution prevention. Treatment technologies are similar to those found in Ontario and U.S. refineries. In general, effluent quality regulations are less stringent than those found in Ontario and are based solely on concentrations.

Japan recognizes the need for improving environmental quality and is currently developing stricter regulations.

4.0 PERFORMANCE ASSESSMENT OF TECHNOLOGIES

The performance of best available treatment technologies (presented in Section 2.0) are described in this section. Included are the following:

- In-plant Treatment Technologies:

  steam stripping
  neutralization
  catalytic reformer wastewater treatment

- End-of-pipe Treatment Technologies:

  preliminary treatment
  biological treatment
  effluent polishing

- Advanced Treatment Technologies:

  granular activated carbon
  powdered activated carbon
  membrane technologies
  ozone and ozone/UV
  evaporative technologies

- Pollution Prevention Measures

  source control
  cooling water systems
  storm water management

For each technology, performance data is presented, an evaluation of the quality of this data is undertaken, and a conclusion as to whether the technology, or technology train, can be considered demonstrated technology. The definition of demonstrated technology is as follows:

> A technology can be considered a demonstrated technology if data on the technology is available and that data can be used to predict, with a reasonable degree of confidence, the reliability of the technology and the performance of the technology with respect to contaminant reductions and effluent variability at any plant in the sector or sub-sector, given the expected variability between plants, and could be successfully retrofitted into existing facilities with a reasonable degree of confidence.

4.1 IN-PLANT TREATMENT TECHNOLOGIES

4.1.1 Steam Stripping

Steam stripping is commonly used to remove sulfides and ammonia. With a properly designed unit sulfide and ammonia concentrations of less than 1.0 and 5.0 mg/l, respectively can be achieved in the stripper effluent. Esso Nanticoke refinery has reportedly achieved levels even less than these. With influent concentrations of 900 ppm and 1,900 ppm for sulfides and ammonia, respectively, the Esso Nanticoke unit was able to achieve effluent concentrations of 0.2 ppm and 3.5 ppm, respectively (Cameron, 1979).

Steam strippers can also be used as an in-plant technology to remove volatile and semi-volatile organic pollutants from selected waste streams. No refineries are currently using steam strippers in this fashion, but they are commonly used in the organic chemicals industry.

Data from selected U.S. organic chemical plants are presented in Table 27. The steam stripper effluent performance data are from the U.S. EPA study of the organic chemical industry. For comparison purposes, data on toxics in typical API separator effluents are also presented.

This information shows that there is no available data that demonstrates that in-plant steam stripping can reduce specific toxic organic pollutants in wastewasters to levels below that already achieved by secondary treatment systems. Therefore, steam stripping is considered demonstrated technology for the treatment of ammonia, sulfides and phenolics but not for the treatment of other toxic organic pollutants.

4.1.2 Neutralization of Spent Acids and Caustics

By neutralizing acidic and caustic wastestreams, proper pH ranges can be maintained in the end-of-pipe process wastewater treatment system. This is common usage, and is a demonstrated technology in Ontario refineries.

4.1.3 Catalytic Reformer Wastewater Treatment

Granular activated carbon can be used for the in-plant treatment of catalytic reforming wastewaters for removal of CDDs/CDFs by adsorption. Shell and Suncor refineries in Ontario have temporarily installed activated carbon treatment facilities and are in the process of obtaining Certificates of Approval for permanent facilities. Treatability and performance data from these systems indicate consistently high removal rates for CDDs and CDFs (>95%), with some contaminant levels non-detectable. Both companies have recently reported having consistent removal to non-detectable levels in the low parts per quadrillion range (ppq). These levels are generally considered state-of-the-art for analytical determinations.

The treatability and performance data discussed above demonstrate that activated carbon treatment is possibly a demonstrated technology, but more analytical data is needed to establish specific reliable limits. As of this writing, data from Ontario refineries is being collected for this purpose.

TABLE 27

STEAM STRIPPING PERFORMANCE DATA

Source:	Performance Data* U.S. EPA OCPSF Study[1]			API Separator Effluent Quality U.S. EPA Petroleum Refining Study[2]			
EPA # Pollutant Name	Long Term Ave., ppb	Maximum Monthly Ave. VF	Maximum Daily Ave. VF	Range of Detected Values, ppb	No. of Plants Sampled	Total Samples Analyzed	Total Times Detected**
8 1,2,4-Trichlorobenzene	64.7218	3.02524	12.2662		10	15	0
9 Hexachlorobenzene	64.7218	3.02524	12.2662		10	15	0
10 1,2-Dichloroethane	64.7218	2.77681	8.8604		9	10	0
12 Hexachloroethane	64.7218	3.02524	12.2662		10	15	0
14 1,1,2-Trichloroethane	10.2931	3.02524	12.2662		9	10	0
25 1,2-Dichlorobenzene	64.7218	3.02524	12.2662		10	15	0
32 1,2-Dichloropropane	64.7218	3.02524	12.2662		9	10	0
33 1,3-Dichloropropene	64.7218	3.02524	12.2662		9	10	0
42 Bis(2-Chloroisopropyl) Ether	64.7218	3.02524	12.2662		10	15	0
44 Methylene Chloride	10.8000	3.27366	15.6720	4-1600 (>100)***	9	10	9***
52 Hexachlorobutadiene	64.5000	3.02524	12.2662		10	15	0
56 Nitrobenzene	948.675	2.35797	6.7477		10	15	0
4 Benzene	28.5761	1.9743	4.65485	>100-2434 (>100)	9	10	9
6 Carbon Tetrachloride	64.5000	2.18759	5.88383		9	10	0
7 Chlorobenzene	64.5000	2.18759	5.88383		9	10	0
11 1,1,1-Trichlorobenzene	10.00	2.18759	5.88383		9	10	0
13 1,1-Dichloroethane	10.00	2.18759	5.88383		9	10	0
16 Chlorobenzene	50.00	2.18759	5.88383		9	10	0
23 Chloroform	44.1081	2.49394	7.3623	<5-100	9	10	6
26 1,3-Dichlorobenzene	64.5000	2.18759	5.88383		10	15	0
27 1,4-Dichlorobenzene	64.5000	2.18759	5.88383		10	15	0
29 1,1-Dichloroethylene	10.0517	2.18759	5.88383		9	10	0
30 1,2-Trans-Dichloroethylene	11.0517	2.18759	5.88383	20	9	10	1
38 Ethylbenzene	64.5000	2.18759	5.88383	28-812 (>100)	9	10	7
45 Methyl Chloride	50.00	2.18759	5.88383		9	10	0
85 Tetrachloroethylene	18.4286	2.78458	8.85657	>50	9	10	1
86 Toluene	12.4177	2.18759	5.88383	96-11,767 (>100)	9	10	9
87 Trichloroethylene	11.5862	2.18759	5.88383		9	10	0
88 Vinyl Chloride	64.5000	1.49754	2.6616		9	10	0

Notes:

* For pollutants without performance data provided in the OCPSF study, the average of the values for given pollutants was used (as was done in the original OCPSF study data.)

** Laboratory analysis reported as less than a detection limit is considered not detected (value = 0) for this table.

*** Probable sampling and/or analysis contamination.

Source:

1. Development Document for Effluent Limitations Guidelines and Standards for the Organic Chemicals, Plastics and Synthetic Fibers Industry, October, 1987. EPA Doc. No. 440/1-87/009.

2. Development Document for Effluent Limitations Guidelines and Standards for the Petroleum Refining Point Source Category, October, 1982. EPA Doc. No. 440/1-82/014.

4.2 END-OF-PIPE TREATMENT TECHNOLOGIES

4.2.1 Preliminary Treatment

Preliminary end-of-pipe treatments include equalization to avoid shock loads to the biological treatment system, chemically-assisted dissolved or induced air flotation to remove free and emulsified oils and, in some cases, filtration to remove solids. These technologies generally produce effluents with levels between 5-15 mg/l for oil and grease, as well as TSS. Chemical precipitation can reduce toxic metal concentrations to less than 1 mg/L (Barnes, 1984). Data from a U.S. EPA study of the metal finishing industry are presented in Table 28.

Preliminary treatment is a common practice at all petroleum refineries. It is used to both remove selected pollutants (i.e. oil and grease and TSS) and to equalize pollutant loading to the biological treatment system. As such, they are demonstrated technologies. However, since toxic metals are already at low concentrations (compared to their solubility), it is not demonstrated that chemical precipitation will improve effluent quality for toxic metals.

4.2.2 Biological Treatment

The performance of an individual activated sludge system for biological treatment will vary for each refinery dependent upon the type and size of the system and flow and contaminant load. Table 29 presents a summary of selected performance data from Ontario and the United States. It is important to note that these data include the performance of any polishing system in place at each refinery. These data are for full-scale systems and are either from the MISA monitoring program or from the U.S. NPDES permit reporting system. All of these data are of high quality.

4.2.3 Effluent Polishing

Effluent polishing with filters, polishing ponds, or both aids in removing residual suspended matter carried over from the secondary clarifiers. Organic materials contributing to BOD and certain toxic organic pollutants may be adsorbed onto the solids. According to one study, filtration can reduce suspended solids to less than 5 ppm (Kempling and Eng, 1977). Effluent quality in this range is routinely attained at the Esso Nanticoke refinery, which has filters and polishing ponds. Performance data for just polishing ponds are not available, but are included as part of the data results presented in Table 29.

TABLE 28

CHEMICAL PRECIPITATION PERFORMANCE DATA

Source:	Performance Data U.S. EPA OCPSF[1]/Metal Finishing			Separator Effluent Quality U.S. EPA Petroleum Refining Study[2]			
EPA # Pollutant Name	Long Term Ave., ppb	Maximum Monthly Ave. VF	Maximum Daily Ave. VF	Range of Detected Values, ppb	No.of Plants Sampled	Total Samples Analyzed	Total Times Detected*
119 Total Chromium	572	1.934	4.85	<1-2548	10	92	80
120 Total Copper	815	1.781	4.15	<5-286	10	79	61
121 Total Cyanide	180	2.343	6.68	3-1125	10	47	38
122 Total Lead	197	1.642	3.52	3-862	10	81	39
124 Total Nickel	942	1.796	4.22	2-154	10	78	17
128 Total Zinc	549	1.912	4.75	11-872	10	100	89

Notes: * Laboratory analysis reported as less than a detection limit is considered not detected (value = 0) for this table.

Source: 1. Development Document for Effluent Limitations Guidelines and Standards for the Organic Chemicals, Plastics and Synthetic Fibers Industry, October, 1987. EPA Doc. No. 440/1-87/009 (transferred from the metal finishing industry).

2. Development Document for Effluent Limitations Guidelines and Standards for the Petroleum Refining Point Source Category, October, 1982. EPA Doc. No. 440/1-82/014.

TABLE 29

BIOLOGICAL TREATMENT PERFORMANCE DATA

POLLUTANT (mg/l)	AVG. OF ONTARIO	BEST OF ONTARIO (Nanticoke)	AVERAGE OF 7 IN U.S.	BEST OF 7 IN U.S.
TSS	22	7	31	11
COD	49.2	30.6	85	58
O & G	2.17	1.58	4.08	1.79
NH_3 (N)	1.7	0.34	5.21	0.1
Sulfide	0.08	0.04	< 0.03	ND
Phenols (4AAP)	0.0110	0.0038	0.047	0.0038
CrT	0.0068	0.0016	0.028	0.010
Lead	0.0041	0.0004	< 0.02	< 0.005 (max)
Zinc	0.29	0.027	0.09	< 0.005 (max)
Benzene	0.0008	0.0003	< 0.005	< 0.004 (max)
Toluene	0.0007	0.0003	< 0.004 (max)	< 0.006 (max)
Naphthalene	0.0011	0.0004	< 0.003 (max)	< 0.003 (max)
Copper	0.0048	0.0029	< 0.012	< 0.006 (max)
Nickel	0.0034	0.0012	< 0.08	0.036

4.3 ADVANCED TREATMENT TECHNOLOGIES

4.3.1 Granular Activated Carbon

Adsorption on GAC can be used for effluent polishing following biological treatment for removal of residual BOD and trace level toxic organic pollutants. Limited data for treatment of petroleum refinery wastewaters (pilot-scale data) with GAC are presented in Table 30.

GAC used in place of conventional biological treatment was referenced in the Petroleum Refining Development Document, October, 1982. One refinery used activated carbon as the main treatment process with no biological treatment. The refinery reported operating problems and intended to replace the GAC system with conventional biological treatment.

Since there is insufficient available data, either pilot- or full-scale, to predict performance with a satisfactory level of confidence, this technology is not considered to be demonstrated.

4.3.2 Powdered Activated Carbon

Limited performance data for the treatment of petroleum refinery wastewaters with PAC are presented in Table 31. One study, in which four parallel systems were operated, compares GAC and PAC systems to standard conventional biological treatment. Performance data are shown in Table 32. The GAC system performed better for nearly all parameters. The data presented in Tables 31 and 32 are a mixture of full-scale tests and pilot-plant data. The QA/QC for these data are unknown.

As with GAC, there is insufficient data to predict performance with a satisfactory level of confidence. In addition, PAC does not appear able to improve the performance of existing biological treatment systems in Ontario.

4.3.3 Membrane Technologies

Reverse osmosis and ultrafiltration are pressure membrane technologies that can be used to separate chemical constituents from aqueous streams. Although these technologies can be quite effective, a principal drawback is that the separated components are concentrated in a reject aqueous stream which may comprise from 5 to 20 percent of the original flow. There are no existing membrane systems being used on refinery effluents.

Since there is insufficient data to predict performance with a satisfactory level of confidence, this technology is not considered demonstrated.

4.3.4 Ozone and Ozone/UV Technologies

Although ozone and ozone/UV can remove phenolic and other toxic organic compounds, there are no refineries currently using this technology. As a result, there is insufficient data to predict performance with a satisfactory level of confidence. Therefore, these technologies are not demonstrated.

TABLE 30

GRANULAR ACTIVATED CARBON PERFORMANCE DATA

Compound Class	Concentration Range in DAF Effluent (ppb)	Percent Removal Range by Activated Sludge Unit	Average Percent Removal by Activated Sludge Unit	Percent Removal Range by Activated Carbon Unit	Average Percent Removal by Activated Carbon Unit
Alkanes	11-683 (27)	99.33-99.98	99.65 (25)	58.8-97.9	83.5 (18)
n-Alkanes	11-683 (21)	99.33-99.98	99.58 (19)	70.2-97.9	85.9 (15)
Branched Alkanes	67-246 (6)	99.73-99.96	99.88 (6)	58.8-78.7	71.9 (3)
Cycloalkanes	21-71 (10)	99.76-99.98	99.81 (10)	NM	NM
Alkylated Benzenes	5-187 (23)	99.94-99.99	99.97 (18)	44.9-77.3	66.5 (8)
Toluene	101 (1)	99.87	99.87 (1)	84.1	84.1 (1)
C_2-Benzenes	35-187 (3)	99.95-99.97	99.96 (3)	66.7-77.3	73.5 (3)
C_3-Benzenes	5-176 (7)	99.94-99.98	99.97 (6)	44.9-71.2	58.7 (3)
C_4-Benzenes	8-64 (12)	99.96-99.99	99.98 (8)	51.4	51.4 (1)
Alkylated Indans, Tetralins	11-104 (18)	99.93-99.99	99.98 (10)	50.0	50.0 (1)
Alkylated Naphthalenes	21-448	99.69-99.99	99.93 (20)	12.0-69.8	49.4 (13)
Naphthalene	197	99.99	99.99 (1)	37.7	37.7 (1)
Methyl Naphthalenes	259-448	99.99	99.99 (2)	33.3-44.9	39.1 (2)
C_2-Naphthalenes	45-267	99.94-99.98	99.98 (6)	12.0-55.8	34.1 (5)
C_3-Naphthalenes	21-160	99.69-99.97	99.89 (11)	45.2-69.8	71.1 (5)
Alkylated Benzothiophenes & Dibenzothiophenes	8-32	99.81-99.93	99.88 (8)	71.4-82.9	77.1 (2)
Alkylated PNAs	3-168	99.65-99.99	99.86 (10)	52.8-76.1	64.5 (2)

NM - Not Measured

( ) Number of compounds

Source: Raphaelian, L., and Harrison, W. 1978. Trace Organics Variation Across the Wastewater Treatment System of a Class-B Refinery and Estimate of Removal of Refractory Organics by Add-on Mixed-Media Filtration and Granular Activated Carbon at Pilot Scales: DOE/EPA Interagency Energy/Environment R&D Program Rept. EPA-600/7-78-125.

TABLE 31

POWDERED ACTIVATED CARBON PERFORMANCE DATA

	SOURCE										
	1A	1B	1C	2	3A	3B	3C	4	5	AVE.*	MAX.
COMMON PARAMETERS (mg/l)											
PAC	1000	1000	1000	1000	100	50**	25**	+4000**	1600		
BOD	15	13.5	3						10		15
COD	135	183	112	250					41.1	145	250
TOC				83					37.5	60	83
TSS	50	72	42						26.7	41	72
O&G								1	1.2	1.1	1.2
Total Cyanide									<0.05	<0.05	<0.05
Phenols					0.001	0.002	0.006	0.034	0.016	0.018	0.034
SOC					16.0	12.0	16.0	13		14	16.0
SCOD					40.3	27.5	50.3	44		42	50.3
NH_4 - N								3.1		3.1	3.1
NH_3 - N					0.2	0.1	0.4		7.6	4	7.6
OTHER POLLUTANTS (mg/l)											
Arsenic									<0.010	<0.010	<0.010
Selenium									<0.010	<0.010	<0.010
Cadmium									<0.001	<0.001	<0.001
Copper									0.018	0.018	0.018
Antimony									<0.010	<0.010	<0.010
Chromium									0.1	0.1	0.1
Nickel									0.014	0.014	0.014
Zinc									0.14	0.14	0.14
Silver									<0.010	<0.010	<0.010
Thallium									<0.010	<0.010	<0.010
Lead									0.018	0.018	0.018
Mercury									<0.001	<0.001	<0.001
Chloroform									<0.010	<0.010	<0.010
Benzene									<0.040	<0.040	<0.040
Ethylbenzene									<0.010	<0.010	<0.010
Toluene									<0.010	<0.010	<0.010
Pyrene									<0.010	<0.010	<0.010
Chrysene									<0.010	<0.010	<0.010
Naphthalene									<0.010	<0.010	<0.010
Fluorene									<0.010	<0.010	<0.010
Bis(2-ethylhexy)-phthalate									<0.016	<0.016	<0.016

*Values are first averaged within each study, then averaged against the other studies.

**Experimental high-surface area carbon.

Sources:

1 Rizzo, J.A. 1976. Activated Carbon Clears Effluent. Oil & Gas Journal, Vol. 74, No. 22. 1976. pp. 52-56.

2 Thibault, G.T., Tracy, K.D., and Wilkinson, J.B. 1977. Evaluation of Powdered Activated Carbon Treatment for Improving Activated Sludge Performance. Proc. API-Refining Dept. Meeting, Chicago. 1977. pp. 235-241.

3 Stenstrom, M.K. and Grieves, C.G. 1977. Enhancement of Oil Refinery Activated Sludge by Addition of Powdered Activated Carbon. Proc. 32nd Industrial Waste Conference, Lafayette, IN. 1977. pp. 196-205.

4 Grieves, C.G., Crame, L.W., Vernardos, D.G., and Ying, Wei-chi. 1980. Powdered Versus Granular Carbon for Oil Refinery Wastewater Treatment. J. Water Pollut. Control Fed., Vol. 52, No. 3. 1980. pp. 483-497.

5 McBride, J.S., Knecht, A.T., Bevan, S.A., and Muhlbaier, D.J. 1982. The Effect of Powdered Activated Carbon in a Petroleum Refinery Activated Sludge Treatment System. R.S. Kerr Environ. Res. Lab, U.S. EPA, Report No. EPA-600/2-82-076. 1982.

TABLE 32

COMPARISON OF PERFORMANCE OF POWDERED AND GRANULAR ACTIVATED CARBON TREATMENT SYSTEMS

	ARITHMETIC AVERAGE CONCENTRATIONS (mg/l) OF COMBINED DATA FROM ALL THREE 30-DAY TEST PERIODS					
	TOC	COD	Phenols	O&G	NH_3	TSS
INFLUENT WASTEWATER	139	415	---	85	---	82
WASTEWATER AFTER PRETREATMENT	124.5	380	7.0	18	15.7	7.4
FINAL EFFLUENT, CONVENTIONAL SYSTEM (b)	43.5	117.5	0.19	4.1	0.18	8.0(a)
FINAL EFFLUENT GA SYSTEM (c)	21.5	44.8	0.08	3.1	0.10	---
FINAL EFFLUENT COMMERCIAL PAC SYSTEM (d)	30.7	66.5	0.09	3.8	0.17	2.6(a)
FINAL EFFLUENT EXPERIMENTAL PAC SYSTEM (e)	23.0	44.7	0.09	3.8	0.07	2.3(a)

NOTES:

(a) Third 30-day test period only.
(b) Conventional system: activated sludge and final filtration.
(c) GAC system: conventional activated sludge, final filtration and GAC contactors.
(d) Commercial PAC system: commercially available PAC added to activated sludge system and final filtration.
(e) Experimental PAC system: experimental high-surface-area PAC added to activated sludge system and final filtration.

Source:

Borey, R.B. and, Henderson, U.V. Jr., 1981, Pilot Studies on the Toxicity of Effluents from Conventional and Carbon Enhanced Treatment of Refinery Wastewater - Phase III. Port Arthur Res. Lab., API Publ. No. 958, 1981.

4.3.5 Evaporative Technologies

Vapor compression distillation with recycle is an evaporative technology that can achieve zero discharge of wastewater to receiving waters. However, pollutants are not eliminated, but rather are transferred to either the air or become a solid waste. This technology requires a high initial investment and high operating costs.

Since there is insufficient information to determine the reliability of this technology, and to determine whether it can be successfully retrofitted, this evaporative technology is not considered demonstrated.

4.4 POLLUTION PREVENTION MEASURES

4.4.1 Source Control

Source control measures including wastewater segregation, boiler condensate recovery, treated effluent reuse, and other general measures can be very effective in reducing the amount and level of contamination of refinery wastewater effluent.

To calculate the achievable reduction in refinery wastewater flow, a full investigation of each refinery would be required. However, some general performance data is available. According to the Langer study, 26% of process wastewaters at 12 refineries were generated from boiler systems. Optimal recovery and reuse in 10 plants could potentially reduce these wastes by an average of 40%. In addition to the benefits of wastewater reduction are savings in raw water and treatment costs, and reduced energy requirements with the recovery of high temperature condensate.

Also in the Langer study are data regarding treated effluent reuse. In 10 of 12 refineries, an average of 45% of the treated effluent could be reused (Langer, 1983). The API report also confirms the high potential for treated effluent reuse (API, 1977).

Wastewater segregation and other general measures are more difficult to quantify and, again, are refinery dependent.

Based upon this information, it is believed that although extensive flow reductions can be attained, it cannot be substantiated that all Ontario refineries can meet the extensive flow reduction achieved by Esso Nanticoke. Nanticoke has achieved its low flow by incorporating low water usage techniques into its original design; not all of these techniques may be retrofittable, including complete sewer segregation and air cooling. A complete and detailed water balance of each Ontario refinery would be needed to determine whether retrofit flow reduction schemes could be used to achieve Nanticoke's level of low water usage.

4.4.2 Cooling Water Systems

For the complete elimination of cooling water, systems incorporating recirculated cooling water and/or once through cooling water may be converted to up to 100% air cooling. However, the high costs, high energy requirements and high noise levels of air cooling systems may prohibit this conversion. In addition, there still can be leaks to the atmosphere through air/water heat exchange failures.

Due to space limitations and existing process technology, which is designed around water cooling, it may not be possible to replace all cooling water systems in older refineries, greatly limiting this technology's applicability in Ontario. Therefore, conversion to 100% air cooling has not been demonstrated.

Once Through Cooling Water Systems

Once through cooling water systems can also be upgraded. Dechlorination using sulfide or sulfite compounds will increase effluent quality. In addition, improved leak detection and management practices for controlling leaks and spills will also serve to reduce the presence of toxics in once through cooling water system discharges. These practices are becoming common practice in Canada and the United States.

Cooling Tower Systems

Recirculated cooling systems can be improved by reducing the rate of cooling tower blowdown and by eliminating the use of toxic chemical additives in the cooling water. However, at present, the effects of dechlorination chemicals on fish toxicity are not known.

For cooling tower systems, according to the Langer study, in 12 of the plants studied, refinery personnel estimated 25-75% of the blowdown could potentially be controlled and reduced. The cycles of concentration for these refineries ranged from 1.1 to 9.5, and averaged 4. In six of the plants, the study estimated blowdown could be reduced by more than 50% (Langer, 1983).

The reduction of toxicity of blowdown from converting from zinc and chromate based treatment chemicals to organic compounds is widely known in this industry.

4.4.3 Storm Water Management

Improved storm water segregation can significantly reduce the amount of wastewater treated in the system. Complete segregation of storm water falling outside of the immediate process areas should be practiced, however, it may be costly to implement. Ideally, only storm water falling in process areas should be treated with process wastewaters.

Complete segregation is not a demonstrated technology. It is based upon technology that is designed into the original construction of new refineries, and it cannot be demonstrated that extensive retrofitting can be accomplished at older refineries.

5.0 IDENTIFICATION OF BAT OPTIONS FOR ONTARIO

Based upon a preliminary analysis at the beginning of this project, nine options were identified for the regulation of process wastewater, three for once through cooling water systems, three for cooling tower systems, and two for storm water. These options were identified prior to the collection of data, and prior to evaluating the technology options as to whether they meet the definition of a demonstrated technology, which is as follows:

> A technology can be considered a demonstrated technology if data on the technology is available and that data can be used to predict, with a reasonable degree of confidence, the reliability of the technology and the performance of the technology with respect to contaminant reductions and effluent variability at any plant in the sector or sub-sector, given the expected variability between plants, and could be successfully retrofitted into existing facilities with a reasonable degree of confidence.

5.1 ORIGINAL BAT OPTIONS

The original list of options is as follows:

5.1.1 Process Wastewater

Option 1 is U.S. BAT/BPT with the addition of the in-plant treatment of catalytic reformer scrubber wastewater with granular activated carbon.

Option 2A is the average flow and average effluent concentrations for all refineries in Ontario.

Option 2B is based on the best refinery in Ontario (Esso Nanticoke). As in Option 2A, this option also reflects the treatments based in Option 1, however a reduction by 52% in calculated BPT wastewater flow ratios is required to match that achieved by Esso Nanticoke. The flow basis for the limits would therefore be 52% more stringent than U.S. BPT. In addition, the regulation would also be based on the effluent concentrations achieved by Nanticoke, which is also more stringent than U.S. BPT concentration values.

Option 3 reflects the best refinery in the world. Based on available information, this is Esso's Nanticoke refinery. This option is therefore the same as Option 2B.

Option 4 is the technology that produces non-toxic effluent. Currently, all Ontario refineries discharge non-toxic or extremely low toxic effluents. Therefore, this option is also the same as Option 1, 2A and 2B.

Option 5A1 (and Options 5A2 through 5B) is designed to move the sector toward zero toxic effluent by the addition of advanced treatment technologies. In Option 5A1, this goal would be achieved by adding to Option 2B:

Steam stripping in-plant for VOC control,
Chemical precipitation for metals removal, and
Granular activated carbon for end-of-pipe filtration following the biological treatment plant.

Option 5A2 is designed to advance the sector toward zero toxic effluent by adding to Option 2B:

Steam stripping in-plant for VOC control,
Chemical precipitation for metals removal, and
Powdered activated carbon addition to the activated sludge in the biological treatment process.

Option 5A2 Modified would advance the sector toward zero toxic effluent by adding to Option 2B powdered activated carbon in the biological treatment process. (Steam stripping and chemical precipitation are not included.)

Option 5B would advance the sector toward zero discharge by adding (to existing treatment systems) evaporation technology using vapor compression distillation with condensate recycle.

5.1.2 Once Through Cooling Water System Options

Option 1 continues with the existing technologies employed at each refinery.

Option 2 incorporates improvements into the existing systems as described below:

Dechlorination of once through cooling water effluents by adding sulfide or sulfite compounds.

Leak detection by the installation of automated detection systems for identification of VOC's and/or oil streams.

Best Management Practices for the control of leaks and spills.

Option 3 converts all once through cooling water systems to air cooled systems resulting in zero discharge of cooling water to surface waters.

5.1.3 Cooling Tower System Options

Option 1 continues with existing refinery practices.

Option 2 eliminates toxic chemical additives to the cooling tower water and increases cooling water recirculation to the range of 4-6 cycles.

Option 3 converts all cooling tower systems to air cooled systems resulting in zero cooling water discharge to surface waters.

5.1.4 Storm Water Options

Option 1 continues existing refinery practices.

Option 2 is complete segregation of storm water, similar to Esso Nanticoke where only storm water falling in process areas is routinely treated.

Since the cost analyses were also completed prior to the collection of data and prior to determining which options were actually demonstrated for use in this industry, cost data for all of the above options are included in Chapter 6 and Appendix A.

5.2 DEMONSTRATED TECHNOLOGY EVALUATION

Based upon the analyses presented in Section 4, the following technologies are now not considered to be demonstrated for use in Ontario:

5.2.1 Process Wastewater

Steam stripping for specific toxic organics removal

Data for this technology does not show performance to be better than typical secondary treatment.

Chemical precipitation for metals removal

Data for this technology also fails to demonstrate better performance than typical secondary treatment.

Granular and powdered activated carbon treatment

There is insufficient data to predict performance with a satisfactory level of confidence for Ontario refineries. In addition, data for this technology does not show performance to be better than typical secondary treatment.

Membrane technologies

The data available for this technology is also insufficient to predict performance with sufficient confidence needed for a BAT analysis.

Ozone and ozone/UV

The data available for this technology is also insufficient to predict performance with sufficient confidence needed for a BAT analysis.

Evaporative technologies

There is insufficient information to determine the reliability of this technology and to determine whether this technology can be successfully retrofitted.

Source control

Based upon information obtained, it is believed that although extensive flow reductions can be attained, it cannot be substantiated that all Ontario refineries can meet the extensive flow reduction achieved by Esso Nanticoke. Nanticoke has achieved its low flow by incorporating low water usage techniques into its original design; not all of these techniques may be retrofittable, including complete sewer segregation and air cooling. A complete and detailed water balance of each Ontario refinery would be needed to determine whether retrofit flow reduction schemes could be used to achieve Nanticoke's level of low water usage.

TABLE 33

PERFORMANCE OF OPTIONS

POLLUTANT (mg/l)	AVG. OF ONTARIO	BEST OF ONTARIO (Nanticoke)	AVERAGE OF 7 IN U.S.	BEST OF 7 IN U.S.	OPTION 1: U.S. BAT/BPT	OPTION 5A2: (MODIFIED) PWDRD. A/C
TSS	22	7	31	11	10	41
COD	49.2	30.6	85	58	100	145
O & G	2.17	1.58	4.08	1.79	5	1.1
NH_3 (N)	1.7	0.34	5.21	0.1	6	4
Sulfide	0.08	0.04	0.03	ND	0.1	
Phenols (4AAP)	0.0110	0.0038	0.047	0.0038	0.1	0.018
CrT	0.0068	0.0016	0.028	0.010	0.25	0.1
Lead	0.0041	0.0004	< 0.02	< 0.005 (max)	0.024	0.018
Zinc	0.29	0.027	0.09	0.005 (max)	0.231	0.14
Benzene	0.0008	0.0003	< 0.005	< 0.004 (max)	0.002	< 0.04
Toluene	0.0007	0.0003	< 0.005 (max)	< 0.004 (max)	0.002	< 0.01
Naphthalene	0.0011	0.0004	< 0.003 (max)	< 0.0003 (max)	< 0.001	< 0.01
Copper	0.0048	0.0029	< 0.012	< 0.036 (max)		
Nickel	0.0034	0.0012	< 0.08	0.036		

Table 33 presents a summary of performance data for selected technology options presented above. The following conclusions can be drawn from these data:

Toxics:

Across all options, there is no significant difference in effluent concentrations for toxics.

Most toxics (such as benzene, toluene) were found at or below detection levels in refinery effluents for all options.

There are some toxic pollutants found in most effluents, but at low levels (levels near detection).

Non-Toxics:

For some pollutants, U.S. BPT/BAT is still the most stringent.

For other non-toxic pollutants, more stringent options may apply (eg. COD).

Flow:

Therefore, flow reduction seems to be the most significant factor in reducing discharge pollutant loadings.

5.2.2 Cooling Water

For once through cooling and cooling tower systems, 100% air cooling has not been demonstrated because it is not believed that this technology can be successfully retrofitted into older refineries. This is primarily due to space availability and retrofitting problems with existing process technology.

5.2.3 Storm Water

Complete segregation is also not a demonstrated technology. It is based upon technology used at new refineries, and it cannot be demonstrated that extensive retrofitting can be accomplished at older refineries.

5.3 DEMONSTRATED BAT OPTIONS

Resulting from the above evaluations of technologies, the following remain as viable, demonstrated, options for the discharge of wastewater from Ontario petroleum refineries:

5.3.1 Process Wastewater

Option 1
Option 2A

5.3.2 Once Through Cooling Water System Options

Option 1
Option 2

5.3.3 Cooling Tower System Options

Option 1
Option 2

5.3.4 Storm Water Options

Option 1

6.0 BEST AVAILABLE TECHNOLOGY COST ESTIMATES

6.1 INTRODUCTION

This section addresses the cost estimates (Appendix A) associated with the control and treatment of best available technologies (BAT Options) presented in Section 5.1. Total and incremental costs estimates as well as land requirements are presented for each refinery. Capital cost estimates include equipment and installation, engineering and contingencies as well as retrofitting cost where applicable. Operating cost estimates include maintenance and operating labor, power, material and chemicals, taxes and insurance and administrative costs. All cost estimates are based upon 1989 Canadian dollars.

The sources for the cost estimates for each technology considered under the BAT Options are presented below:

Technology	Source for Cost Estimates
Source Control	Langer, B.S. Wastewater Reuse and Recycle in Petroleum Refineries. Chemical Engineering Progress, May 1983.
Sour Water Strippers	Supplement for Pretreatment to the Development Document for the Petroleum Refinery Industry, EPA 440/1-76/083, December 1976.
Dissolved Air Flotation	CAPDET Computer Program
Equalization	CAPDET Computer Program
Biological Treatment Secondary Clarification	CAPDET Computer Program
Filtration	CAPDET Computer Program
Polishing Ponds	Development Document for Effluent Guidelines and Standards for the OCPSF Industry, EPA 440/1-87/009, October 1987.
Chemical Precipitation	Development Document for Effluent Guidelines and Standards for the OCPSF Industry, EPA 440/1-87/009, October 1987.

Technology	Source for Cost Estimates
Steam Stripping	Development Document for Effluent Guidelines and Standards for the OCPSF Industry, EPA 440/1-87/009, October 1987.
Granular Activated Carbon	Development Document for Effluent Limitations Guidelines and Standards for the Petroleum Refining Industry, EPA 440/1-82/014, October 1982.
Powdered Activated Carbon	Development Document for Effluent Limitations Guidelines and Standards for the Petroleum Refining Industry, EPA 440/1-82/014, October 1982.
Sludge Handling and Disposal	Development Document for Effluent Guidelines and Standards for the OCPSF Industry, EPA 440/1-87/009, October 1987.
Vapor Compression Distillation and Recycle	Development Document for Effluent Guidelines and Standards for the Iron and Steel Manufacturing Point Source Category, EPA 440/1-82/024, May 1982.

The following sections provide a brief description of each technology recommended for the BAT Options with design specifications and associated capital and operating costs estimates.

6.2 SOURCE CONTROL

There are many in-plant control measures designed to reduce or eliminate wastewater flow. Many of these measures, however, require a plant-by-plant evaluation to determine their usefulness. In addition, the costs associated with their implementation are for the most part site dependent, making an accurate estimation of representative costs very difficult.

There is, however, one in-plant flow reduction measure that can be applied at most refineries and whose cost can be readily estimated on the whole industry scale. This flow reduction scheme consists of the recycling of treated refinery wastewaters for use in such process related applications as cooling tower make-up, pump gland cooling water, washdown water, and fire system water. The amount of treated effluent that can be reused depends on the degree to which the effluent is contaminated with dissolved solids.

A study was undertaken to investigate wastewater reuse and recycle techniques in the petroleum refinery industry in the United States (Langer, 1983).

According to this study the cost of treated effluent reuse was investigated for 12 refineries in the United States. The results show that cost per gallon reduction among plants varied substantially, depending on the accessibility of existing treated effluent piping, the availability of existing storage capacity, and the adaptability of existing process equipment to using effluent. In summary, the costs associated with treated effluent reuse can be grouped into two general types. One group includes those refineries whose effluent can be reused directly without additional treatment. Costs for reuse at these refineries include piping, pumping and connection costs, and are based on new underground construction. The other group includes those refineries whose effluent requires additional treatment before reuse. In addition to piping and pumping costs, estimates for these plants include dissolved air flotation, filtration and storage costs (Langer, 1983).

For the purpose of obtaining costs for the Ontario refineries, the second group was utilized. The worst case scenario of all 12 USA refineries studied showed that the costs associated with treated effluent reuse is $1.97 per gallon for capital cost and $0.33 per gallon for annual operating cost. These costs are 1979 dollars and therefore were adjusted by a factor of 1.54 to represent 1989 dollars. In addition, a factor of 1.3 was also applied to account for retrofitting costs for capital costs and finally a factor of 1.15 was also applied to convert U.S. dollars to Canadian dollars.

In order to obtain capital and operating costs for this technology the amount of treated effluent (gallons per day) that needed to be recycled for each refinery in order to meet the particular BAT option target (i.e., best Ontario BAT 15 gallons/bbl) was calculated. Based on the amount of effluent that needed to be recycled the capital and operating cost for each refinery were then obtained.

6.3 SOUR WATER STRIPPERS

The major pretreatment process available to the petroleum refining industry for sour water treatment is stripping. Sour water strippers are capable of removing both sulfides and ammonia to the levels required for pretreatment. The source of the cost estimates for this technology is the Supplement for Pretreatment to the Development Document for the Petroleum Refining Industry (EPA, 1976). The costs reported in this document were taken from the "Economics of Refinery Wastewater Treatment" prepared by the American Petroleum Institute. The total capital cost presented in the above U.S. EPA study include the costs of sour water collection and steam supply to the stripper, as well as the cost of stripping facilities themselves. These costs are based on refinery capacity. In order to obtain the capital cost for the Ontario refineries the actual sour water stripper flowrate of each refinery was used to obtain the corresponding refinery capacity (bbl/day). Then the capital cost estimates for each refinery were obtained directly from the cost estimates presented in the above mentioned U.S. EPA study. These costs are in 1972 dollars and therefore were adjusted by a factor of 2.63 to represent 1989 prices. In addition to that a factor of 1.15 was also applied in order to convert for U.S. dollars to Canadian dollars.

The estimated operating costs for sour water strippers are also presented in the Supplement for Pretreatment to the Development Document for the Petroleum Refinery Industry (EPA, 1976). These costs are only representative of actual costs, since the costs incurred by individual refineries can vary greatly depending on the amount of steam used, redundancy of equipment, and distance pumped. Other operating costs, such as treatment of the off-cases and pH adjustment of the sour waters, are not included due to the difficulty in determining a representative value of the entire industrial segment. These factors where applicable, however, can have a significant effect on the total operating cost of sour water stripping. These operating costs are in 1976 U.S. dollars. Again the cost estimates for operating costs were adjusted to represent 1989 Canadian dollars.

6.4 CAPDET COMPUTER PROGRAM

The CAPDET computer program was utilized to obtain cost estimates for four of the technologies considered for the Ontario Refineries BAT Options 1, 2A, and 2B. The program was used to develop capital and operating costs for Dissolved Air Flotation, Equalization, Biological Treatment followed by Secondary Clarification and Filtration.

The U.S. Environmental Protection Agency (EPA), in coordination with the U.S. Army Corps of Engineers, has developed an economical computer procedure for the design and evaluation of wastewater treatment systems (CAPDET) to assist in preliminary wastewater treatment plant design and cost evaluation requirements.

The use of CAPDET in the preparation of facility plans is encouraged by the U.S. EPA and the acceptance of CAPDET cost estimates is accepted with minimum review. Benchmarking and verification of the CAPDET cost estimates revealed that CAPDET cost estimates had been within 15 percent of actual bid data.

The design of the CAPDET program is based on an intensive study of methods and bases of design for each unit. Design and cost data, based on national averages or a base year (1978), are also built into the model as default data and usually need adjustment by the user to reflect time-specific, site-specific and waste-specific conditions more accurately. Another input to the CAPDET program is the description of the wastewater characteristics. This input must include at least the average design flow rate. The program contains built-in or "default" data for all wastewater characteristics. These are mid-range values normally found in domestic wastewater and include biochemical oxygen demand concentration (BOD), suspended solids (SS) concentration, temperatures for both summer and winter conditions, concentrations of nutrients, and maximum and minimum flow rates as ratios of the average flow. The CAPDET user should specify only wastewater characteristics different from the default values. The program will assign default values to all unspecified wastewater characteristics.

Since the design unit cost data build in the CAPDET program are based on 1978 as the base year they were adjusted to represent 1989 dollars. The default values of the program and the updated values used to obtain the cost for the Ontario refineries are presented below:

UNIT COST DATA	DEFAULT (1978 DOLLARS)	VALUES USED (1989 DOLLARS)	UNIT
Building Cost	48.00	76.8	$/sq. ft.
Excavation	1.2	1.92	$/cu. ft.
Wall concrete	207.0	331.2	$/cu. yd.
Slab concrete	91.0	145.6	$/cu. yd.
Marshall & Swift Index	577.0	895.1	-----
Crane Rental	67.0	107.2	$/hr.
Canopy Roof	15.75	25.2	$/sq. ft.
Labor Rate	13.40	21.2	$/hr.
Operator II Labor Rate	7.50	13.86	$/hr.
Electricity	0.04	0.04	$/khr
Lime	0.03	0.05	$/lb
Alum.	0.04	0.07	$/lb.
Iron	0.06	0.10	$/lb.
Polymer	1.62	2.6	
Hand Rail	25.2	40.3	$/ft.
Pipe Installation Labor Rate	14.70	20.8	$/hr.
Engin. News Record Index	2886	4606	-----
Pipe Cost Index	295.2	463.0	-----
Eight Inch Pipe	9.08	14.5	$/ft.
Eight Inch Pipe Bend	86.82	138.60	$/unit
Eight Inch Pipe Tee	128.49	205.40	$/unit
Eight Inch Pipe Valve	1346.16	2153.9	$/unit

Capital costs were calculated based upon total project costs less miscellaneous non-construction costs, 201 planning costs, technical costs, land costs, inspection costs and interest during construction costs. Operation and maintenance costs were obtained directly from initial year O&M costs. The capital and operating costs obtained from each CAPDET run were multiplied by a factor of 1.15 in order to convert U.S. dollars to Canadian dollars. A factor of 1.3 was applied for the incremental capital costs where applicable in order to account for retrofitting costs.

The design specifications used in the CAPDET program for each technology are discussed in the description of each individual technology.

6.5 DISSOLVED AIR FLOTATION

As noted earlier, the CAPDET computer program was used to obtain the capital and annual operation costs for the DAF systems. The design parameters used for the flotation unit are given below.

Air pressure	40 psig
Detention time in float tank	0.5 hours
Solids loading	15.0 lb/sq.ft./day
Hydraulic loading	3.5 gpm/sq.ft.
Recycle time in pressure tank	3.0 min
Percent removal of solids	60 percent
Air/solids ratio	0.02
Float concentration	3 percent
BOD removal	30 percent
COD removal	30 percent
TKN removal	10 percent

The waste influent characteristics used for the DAF design unit are as follows:

Temperature (summer/winter)	23/10	
BOD_5	285	mg/l
Suspended Solids	350	mg/l
COD	710	mg/l
Soluble COD	400	mg/l
Soluble BOD	85.5	mg/l
pH	7.6	s.u.
TKN	65	mg/l
NH_3	50	mg/l
PO_4	18	mg/l
Oil and Grease	1750	mg/l

The cost of a standard 350 sq. ft. air flotation unit was set at $70,720. The program also assumes that the life expectancy of the flotation unit is 30 years.

6.6 EQUALIZATION

The design parameters used in the CAPDET program for the development of costs for the equalization basin with mechanical aeration system are listed below:

O_2 transfer in waste/O_2 transfer in water:	0.9	
O_2 saturation in waste/O_2 saturation in water:	0.9	
Aerator mixing requirements:	0.03	hp/1000 gallons
Standard transfer efficiency:	5.0	lb O_2/hp-hr
Oxygen requirement:	15	mg/l/hr
Pressure correction coefficient:	1.0	
Dissolved oxygen:	2.0	mg/l
Type of basin:		earthen
Depth of basin:	6.0	feet

The program also assumes that the cost of a standard 50 hp high speed mechanical aerator to be $22,340 and the liner cost of the basin at 0.48 $/sq.ft. The life expectancy of the basin is set at 15 years.

The waste influent characteristics used for the equalization unit are as follows:

Temperature (summer/winter):	23/10	°C
BOD_5:	200	mg/l
BOD soluble:	85.5	mg/l
COD:	500	mg/l
COD soluble:	400	mg/l
TSS:	140	mg/l
Volatile solids:	60	percent
pH:	7.6	s.u.
TKN:	58	mg/l
NH_3:	50	mg/l
Oil and Grease:	87.5	mg/l
PO_4:	18	mg/l

6.7 BIOLOGICAL TREATMENT/SECONDARY CLARIFICATION

For the purpose of representing the costs of the biological treatment for the Ontario Refinery Industry the completely mixed activated sludge process followed by secondary clarification has been selected.

The design parameters use in the CAPDET computer program for the complete mixed activated sludge system are as follows:

TYPE OF AERATION:	DIFFUSED AERATOR	
Reaction rate constant:	0.0002	l/mg/hr
Food/microorganism ratio:	1	
Mixed liquor suspended solids (MLSS):	0.5	mg/l
Mixed liquor volatile solids (MSVSS):	4,500	mg/l
Temperature correction coefficient:	3,100	
Effluent BOD soluble:	1.03	mg/l
	25	

The design parameters used for the secondary clarification used with the CAPDET program are as follows:

Type of Clarifier: Circular

TYPE OF CLARIFIER:	CIRCULAR	
Solids loading rate:	20	lb/sq.ft./day
Surface overflow rate:	500	g/sq.ft./day
Underflow concentration:	1.0	percent
Specific gravity of sludge:	1.07	
Weir overflow rate (maximum):	15,000	g/ft./day
Side water depth:	9	ft.
Detention time:	24	hours
Effluent suspended solids:	40	mg/l

The waste influent characteristics used for the biological/secondary clarification unit are as follows:

Temperature (summer/winter):	23/10	°C
BOD_5:	180	mg/l
BOD soluble:	77	mg/l
COD:	480	mg/l
COD soluble:	392	mg/l
Suspended solids:	140	mg/l
Volatile solids:	60	percent
pH:	7.6	s.u.
TKN:	58	mg/l
NH_3:	50	mg/l
Oil and Grease:	87.5	mg/l

The following standard equipment cost prices were used for the biological/clarification treatment system:

Standard slow-speed, pier-mounted 20-hp aerator:	$ 26,080
Standard 12.0-scfm coarse-bubble diffuser:	10.4
Standard 550-scfm swing arm diffuser:	8,000
Standard 3,000 gpm pump and driver unit:	27,600
Standard 90-ft diameter circular clarifier mechanism:	120,000

The program also assumes a 30 year life expectancy for the activated sludge unit and a 15 year life expectancy for the secondary clarification unit system.

6.8 FILTRATION

Important parameters that must be considered in the design of multimedia filters include influent wastewater suspended solids level, solids characteristics, filtration rates, and filter medium characteristics.

The filtration system specifications used in the CAPDET to develop the cost data are as follows:

MEDIA USED	LAYERS	K	POR	D/A	SF	SG
Anthracite	1 layer	6	0.50	0.0046	7.0	1.4
Sand	1 layer	5	0.40	0.0020	8.5	2.65
Garnet Sand	1 layer	4	0.47	0.0010	8.0	2.65
Gravel	1 layer	6	0.60	0.050	6.0	2.65

where,

K = Coefficient of Permeability
POR = Porosity
D/A = Particle Diameter (ft)
SF = Shape Factor
SG = Specific Gravity

Other filtration system specifications used in the CAPDET program include:

Influent Suspended Solids	40	mg/l
Effluent Suspended Solids	16	mg/l
Filtration rate	4	gpm/ft^2
Backwash rate	20	gpm/ft^2
Depth of Filter Bed	9	ft
Approach Velocity	0.005	ft/sec
Backwash time	10	minutes

The waste influent characteristics used in the CAPDET program for the filtration system are as follows:

Temperature (summer/winter)	23/10	°C
BOD_5	36	mg/l
COD	54	mg/l
Suspended solids	40	mg/l
Volatile solids	70	percent
pH	7.6	s.u.
NH_3	40	mg/l
Oil and Grease	5	mg/l

The cost of a standard 784 sq.ft. filter unit was set at $264,000 while the cost of a standard 3,000 gpm pump and driver unit was set at $27,600. It should be noted that where the required filter surface areas are less than 400 ft^2 (or <2.3 MGD flows) the CAPDET uses package filters for economical reasons. For larger plants with required surface areas of greater than 400 ft^2 (or >2.3 MGD), filters with concrete wall construction are used by the CAPDET program. Finally, the program assumes a 20 year life expectancy for "package" plants and a 40 year life expectancy for concrete structure plants.

6.9 POLISHING PONDS

Cost estimates for the polishing pond systems were taken directly from the Development Document for Effluent Limitations Guidelines and Standards for the OCPSF Industry (EPA, 1987).

The capital costs presented in the above U.S. EPA study were estimated based on costs for excavation, earth preparation, and liner installation. Capital costs also include miscellaneous (15%), engineering (15%), and contingencies (15%). A unit cost of $1.20 per cubic yard was assumed for both excavation and earth preparation. The unit cost for liner installation ($0.54/$ft^2$) was obtained directly from manufacturers' recommendations. The total annual operating cost for each system was obtained by assuming the operating cost to be 10 percent of the total capital cost plus sludge disposal expenses at $7,600 per year per MGD flow. A summary of the capital and annual operating costs in 1982 dollars are presented below:

FLOW (MGD)	CAPITAL COST (1982 DOLLARS)	YEARLY OPERATING COSTS (1982 DOLLARS)
0.07	20,300	2,750
0.86	55,500	14,000
1.44	90,700	23,200
5.07	305,000	80,300
10.00	684,000	166,700
20.00	1,402,400	336,800

Source: Development Document for Effluent Limitations Guidelines and Standards for the Organic, Chemicals Plastics and Synthetic Fibers Industry. EPA 440/1-87/009, U.S. Environmental Protection Agency, Washington D.C., 1987.

Since the capital and annual operating costs are presented in 1982 dollars they were adjusted by a factor of 1.204 to represent 1989 dollars and a factor of 1.15 to convert U.S. dollars to Canadian dollars. A retrofitting factor of 1.3 was also included for the incremental capital costs where applicable.

6.10 CHEMICAL PRECIPITATION

Cost estimates for chemical precipitation were also taken from the Development Document for Effluent Guidelines and Standards for the OCPSF Industry (EPA, 1987). These costs are based on sulfide precipitation which was reported as very effective in removing complexed metals at low levels versus the conventional hydroxide precipitation technology.

The capital and operating cost estimates presented in the above U.S. EPA study are summarized below:

Capital and Operating Costs for
Sulfide Precipitation Systems

FLOW (MGD)	CAPITAL COST (1982 DOLLARS)	OPERATING COST (1982 DOLLARS/YEAR)
0.2	347,000	50,400
1.0	582,500	105,600
5.0	1,318,000	342,000
10.0	2,213,000	637,200
20.0	4,247,000	1,191,800

Capital cost estimates include process equipment including a clarification system, insurance, taxes, contingencies, overhead field labor, field construction equipment, materials and tools. Operating costs include power, chemicals, operating and maintenance labor, taxes and insurance.

Cost estimates for the Ontario Refineries for chemical precipitation are based on end-of pipe flow for each refinery. Since the costs presented above were reported as 1982 U.S. dollars they were adjusted by a factor of 1.2 and 1.15 to represent 1989 Canadian dollars.

6.11 STEAM STRIPPING

The cost estimates for steam stripping for the Ontario Refineries were taken from the U.S. EPA study of the OCPSF Industry. According to the Development Document for Effluent Guidelines and Standards for the OCPSF Industry (EPA, 1987) the cost estimates for the steam stripping process were developed by the Water General Corporation, Process Design Manual for the Stripping of Organics, EPA 68-03-3002, October 1983.

The most conservative option (medium strippability) was chosen to obtain the cost estimates for the Ontario Refineries. The costs presented in the U.S. EPA study for the medium strippability option are based on the design of a tray tower since it was determined that sieve-tray towers operate more efficiently and over a wider range of liquid flow rates. The values assigned to the steam stripper design variables for the medium strippability pollutants are presented below:

DESIGN PARAMETER		VALUE	UNITS
CP:	Specific heat of reflux	1.0	cal/g-°K
DIFL:	Liquid-phase diffusivity	9.918×10^{-5}	ft^2/hr
DIFV:	Gas-phase diffusivity of pollutant into water vapor	0.311	ft^2/hr
FC:	Final concentration of organic	0.01	mg/l
G:	Steam rate into tower	0.10 x L (L=liquid feed into tower)	MGD
GAMD:	Activity coefficient of pollutant in organic phase	1.0	unitless
GAMS:	Activity coefficient of pollutant in aqueous phase	3.775×10^{6}	unitless
IC:	Initial concentration of organic	390	mg/l
K:	Vapor-liquid equilibrium constant	37.3	atm/atm
L:	Liquid feed into tower	0.01 - 1.00	MGD
LPRIM:	Latent heat of steam	542.0	cal/g
MU:	Gas-phase viscosity	294.3×10^{-3}	lb/ft-hr
PSI:	Fractional entrainment mass fraction	0.008	mole/mole
PR:	Operating pressure of column	1.0	atm
REFLUX:	Reflux Ratio	0.0	unitless
RHOG:	Vapor density	0.037	lb_m/ft^3
RHOL:	Liquid density	60	lb_m/ft^3
SAFE:	Safety factor for Vm	0.75	unitless
SIGL:	Liquid surface tension	58.9	dyne/cm
TB:	Boiling point of aqueous reflux	100	°C
TR:	Reflux temperature	9	°C
XPRF:	Tray construction indicator	Perforated	unitless

The resulting cost estimates of this analysis which are based on an effluent pollutant concentration of 0.01 ppm are presented below.

FLOW (MGD)	CAPITAL COST ($)	OPERATING & MAINTAINENCE COST ($)
0.010	302,201	11,816
0.050	303,825	23,076
0.075	322,685	48,058
0.100	330,972	73,020
0.500	462,875	471,637
0.750	538,117	720,607
1.000	611,976	969,521

Source: Development Document for Effluent Limitations Guidelines and Standards for the OCPSF Industry. EPA 440/1-87/009, U.S. Environmental Protection Agency, Washington D.C., 1987.

The above capital costs include feed tanks (approximately 24-hour detention time), preheater, distillation column, condenser, decanter and pumps. The operating costs include operation and maintenance labor, maintenance materials, steam energy, and electricity.

In addition to these costs overhead disposal costs were also considered for the final estimates for the steam stripping technology. Based on manufacturer's information, this overhead waste stream flow is estimated to be 1 (one) percent of the total waste stream flow. Estimates of the cost incurred for the disposal of steam stripper overhead were developed based on vendor quotations.

For overhead waste flows of 1,000 gpd or greater, on-site incineration of the steam stripper overhead waste is the most economically practical solution. Prices for hazardous waste incinerators were solicited from manufacturers and were used as a basis for the capital cost estimates. The operating costs were approximated based on fuel oil consumption, labor costs, and an annual parts and maintenance budget of 10 percent of the capital cost.

To apply the steam stripping overhead disposal cost estimates to the costing methodology, ratios were derived between the steam stripper costs generated via a computerized designed program (presented above) and the overhead estimates that were developed via vendor quotations for contract hauling and incineration.

These ratios are as follows:

Overhead Capital ($) = 0.55 (Steam Stripper Capital $)

Overhead O&M ($) = 0.62 (Steam Stripper O&M $)

In order to obtain the steam stripping cost estimates for the Ontario Refineries, the total steam stripping cost reported in the OCPSF Development Document (including the overhead disposal costs) were used. The flow used to estimate each refinery's capital and operating cost was taken at twice the reported sour water stripper flowrate of each plant.

Again, a factor of 1.20 was applied to convert 1982 to 1989 dollars and a factor of 1.15 was also applied in order to convert U.S. dollars to Canadian dollars. Retrofitting costs were taken to be 1.3 of total capital costs where applicable.

6.12 GRANULAR ACTIVATED CARBON

Cost estimates for the Ontario Refineries were transferred directly from the U.S. EPA study for the Petroleum Refinery Industry (EPA, 1982). The granular activated carbon system considered for the U.S. Petroleum Industry consists of one or more carbon columns, each train having three columns operated in series. This design system is consisting of tanks that can be shipped in one piece, thereby minimizing field construction. The use of shop fabricated tanks with similar sizes allows uniformity in cost estimating, especially in developing construction and design engineering estimates. This approach also results in a conservative (larger) estimate, and is considered preferable when considering general industry-wide costs.

The capital and operating costs presented in the above U.S. EPA study for the granular activated carbon units are presented below:

Capital and Operating Cost Estimates
For Granular Activated Carbon Systems

FLOW (MGD)	CAPITAL COST (1977 DOLLARS)	OPERATING COSTS (1977 DOLLARS/YEAR)
0.1	150,000	54,000
1.0	1,160,000	185,000
5.0	4,100,000	417,000
10.0	6,920,000	694,000
20.0	12,700,000	1,238,000

The capital costs presented above include equipment (activated carbon units) cost, pumping, installation, engineering, contingencies, and carbon regeneration costs for the activated carbon systems of flows ≥ 1.0 mgd. The operating costs include carbon make-up, power, pumping, labor, and maintenance costs.

The capital cost for carbon regeneration systems are based on an equipment manufacturer's quotation. Manpower requirements for the operation of the granular carbon absorbers were obtained from the EPA Technology Transfer Series, Carbon Adsorption Manual, October 1973.

Since the above cost estimates represent 1977 dollars a factor of 1.8 was applied (1989 costs). In addition a factor of 1.15 was also applied in order to convert to Canadian dollars. Furthermore, a retrofitting factor of 1.2 was also included for the incremental capital cost estimates. The end-of-pipe flow reported by each facility was used in order to obtain the cost estimates for this technology for each of the Ontario Refineries.

6.13 POWDERED ACTIVATED CARBON

The capital and operating cost estimates for the Powdered Activated Carbon Treatment Technology for the Ontario Refineries were obtained directly from the Development Document for Effluent Guidelines and Standards for the Petroleum Refining Industry (EPA, 1982) and are presented below:

Capital and Operating Cost Estimates
For Powdered Activated Carbon

FLOW (MGD)	CAPITAL COST (1977 DOLLARS)	OPERATING COST (1977 DOLLARS/YEAR)
0.1	43,000	19,900
1.0	100,000	148,400
5.0	1,743,000	397,000
10.0	2,463,000	463,000
20.0	3,557,000	604,000

These cost estimates presented above are based on 150 mg/l carbon dosage rate and they include capital costs for sludge disposal and credit for sludge disposal (operating cost). The capital costs include equipment, piping, installation, engineering, contingency and carbon regeneration costs for systems of ≥5.0 mgd. The operating cost estimates include carbon make-up, power, labor and maintenance.

Since the above cost estimates represent 1977 U.S. dollars they were again adjusted to represent 1989 Canadian dollars. A factor of 1.2 was also included to account for retrofitting costs for the incremental capital cost estimates.

6.14 SLUDGE HANDLING AND DISPOSAL

Sludges are generated by the following wastewater treatment processes considered for the Ontario Refinery Industry: Biological Treatment, Dissolved Air Flotation and Chemical Precipitation. Therefore, the costs for sludge disposal must be part of the costs for these three technologies. The cost estimates for the Ontario Refineries for sludge disposal were obtained directly from the cost estimates developed by the U.S. EPA OCPSF study. According to the Development Document of the U.S. OCPSF industry (EPA, 1987), the belt filter press, followed by fluidized bed incineration treatment system was selected as the basis for sludge handling and disposal for the OCPSF industries.

In order to estimate the capital operating costs estimates for the sludge handling and disposal certain assumptions were made prior to sizing the equipment. These include the following:

Belt Filter Press:

- Long Term Average Influent TSS = 200 mg/l
- Average Feed Sludge Total Solids = 2%
- Discharge Cake Solids Concentration = 20%
- Solids Loading Rate = 500 lbs/hr/meter
- Hydraulic Loading Rate = 45 gpm/meter
- Operating Time = 8 hrs/day

Fluidized Bed Incineration:

- Influent TSS Concentration = 200 mg/l
- Total Solids = 20%
- Volatile Solids = 80%
- Operating Schedule = 3 days/week
- Minimum Incineration Diameter = 4 feet

The resulting capital and operating cost estimates for the sludge handling and disposal systems which include costs for belt filter press and fluidized bed incineration are presented below:

Sludge Handling and Disposal
Cost Estimates

FLOW (MGD)	CAPITAL COST (1982 DOLLARS)	OPERATING COST (1982 DOLLARS/YEAR)
0.5	930,500	200,400
1.0	1,011,500	251,400
5.0	1,319,700	468,700
10.0	1,892,200	704,700
20.0	2,648,200	1,287,400

The above capital cost estimates include equipment costs, pumps, polymer feed systems, piping, and instrumentation, installation, engineering and contingency costs. Annual operating costs were estimated based upon energy, labor, maintenance, taxes and insurance, oil, fuel, and ash disposal.

These cost estimates were reported in 1982 U.S. dollars, therefore they were adjusted by a factor of 1.204 to represent 1989 Canadian dollars. In addition, a retrofitting factor of 1.3 was applied to incremental capital costs where applicable.

6.15 VAPOR COMPRESSION DISTILLATION AND RECYCLE

BAT Option 5B (progress towards virtual elimination) cost estimates for the Ontario refineries are based on vapor compression distillation and recycle. Cost estimates for this treatment technology were taken directly from the Development Document for Effluent Limitations Guidelines and Standards for the Iron and Steel Manufacturing Point Source Category (EPA, 1982).

Since these costs were reported in 1978 dollars they were adjusted by a factor of 1.6 in order to represent 1989 dollars and by an additional factor of 1.15 to represent Canadian dollars. Since land requirements for this technology do not vary with flowrates they were taken to be 0.5 acres for all flow rates (highest reported value 0.45 acres). The reported average end-of-pipe flow of each refinery was used to obtain the capital and operating cost for the Ontario Refineries. The cost estimates for this technology are presented below:

Capital and Operating Costs Estimates for
Zero Discharge Vapor Compression Distillation and Recycle

FLOW (MGD)	CAPITAL COST (DOLLARS)	OPERATING COST (DOLLARS/YEAR)
0.234	5,617,400	625,500
0.342	7,263,400	889,500
0.420	8,109,800	926,850
0.480	9,083,200	1,052,700
1.00	13,889,800	2,015,600
1.04	13,935,792	2,217,700
1.9	26,333,000	4,120,600

REFERENCES

American Petroleum Institute. 1977. Water Reuse Studies. API Publication 949, Washington D.C., 1977. 132 pp.

Barnes, D., Forster, C.F., and Hrudey, S.E. 1984. Surveys in Industrial Wastewater Treatment. Pitman Publishing, Inc., Marshfield, Massachusetts, 1984, 233 pp.

Beckman, S. 1991. Assessment of Oxidation Technologies (Ozone and Ozone/UV) in the Reduction of Phenolic Compounds in Refinery Wastewaters. SAIC, Paramus, New Jersey, 1991.

Bird, Dr. P. 1990. National Rivers Authority. Dec. 13, 1990. Correspondence.

Borey, R.B., and Henderson, U.V. Jr., 1981. Pilot Studies on the Toxicity of Effluents from Conventional and Carbon Enhanced Treatment of Refinery Wastewater - Phase III. Port Arthur Res. Lab., API Publ. No. 958.

Broseliske, G.H. 1990. Ministry of Public Works, Institute for the Purification of Water. Nov. 22, 1990. Correspondence. 3 pp.

Burks, C.C., ed. 1988. Laws to Discourage Polluters Generally Viewed as Satisfactory in 12 Countries Surveyed, But Enforcement Remains Source of Concern. International Environmental Reporter., April 13, 1988, pp. 242-256.

Burnett-Hall, R.H. 1989. Environmental Regulation in the United Kingdom. International Environmental Reporter, September 1989, pp. 461-470.

Cameron, R.D. 1979. The Design and Commissioning of the Wastewater Treating System at Texaco's Nanticoke Refinery. Texaco, Nanticoke, Ontario, June 1979.

CONCAWE. 1988. Trends in Oil Discharged with Aqueous Effluents from Oil Refineries in Western Europe - 1987 Survey. Report No. 3/89, CONCAWE, December 1988.

CONCAWE. 1989. Oil Refineries Waste Survey - Disposal Methods, Quantities and Costs. Report No. 5/89, CONCAWE, March 1989.

CONCAWE. 1989. EC and U.S. Ecotoxicological Regulatory Data Requirements. Report No. 89/54, CONCAWE, September 1989.

CONCAWE. 1990. European Soil and Groundwater Legislation. Implications for the Oil Refining Industry. Report No. 4/90, CONCAWE, July 1990.

de Jong, J. 1990. Management of the River Rhine. Water Environment and Technology. April 1990, pp. 41-51.

Department of the Environment. 1989. Water and the Environment. The Implementation of European Community Directives on Pollution Caused by Certain Dangerous Substances Discharged into the Aquatic Environment. Department of the Environment Circular 7/89, March 30, 1989.

Department of the Environment. 1990. Environmental Protection Act 1990, Part I, The Environmental Protection (Prescribed Processes and Substances) Regulations. Nov. 5, 1990.

Environment Canada. 1990. Environmental Status Report for the Canadian Petroleum Refining Industry. 1987. EPS 1/PN/3, Environment Canada, Ottawa, Ontario, 1990. 105 pp.

EPA. 1973. Carbon Adsorption Manual. Technology Transfer Series. October 1973.

EPA. 1974. Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Petroleum Refining Point Source Category. EPA-440/1-74/014a, U.S. EPA, Washington D.C., 1974.

EPA. 1976. Supplement for Pretreatment to the Development Document for the Petroleum Refinery Industry. EPA 440/1-76/083, U.S. EPA, Washington D.C., December 1976.

EPA. 1982. Development Document for Effluent Guidelines and Standards for the Iron and Steel Manufacturing Point Source Category. EPA 440/1-82/024, U.S. EPA, Washington D.C., May 1982.

EPA. 1982. Development Document for Effluent Limitation Guidelines and Standards for the Petroleum Refining Point Source Category. EPA-440/1-82/014, U.S. EPA, Washington D.C., 1982.

EPA. 1987. Development Document for Effluent Limitations Guidelines and Standards for the Organic Chemicals, Plastics and Synthetic Fibers Industry. EPA-440/1-87/009, U.S. EPA, Washington D.C., 1987.

Europe (Magazine of the European Commission in North America). 1990. Amsterdam: A Good Beginning. January/February 1990, p. 11.

European Commission Recommendation Regarding Methods of Evaluating the Cost of Pollution Control to Industry, Dec. 19, 1978.

European Commission. 1987. The State of the Environment in the European Community 1986. Directorate General for Environment, Consumer Protection and Nuclear Safety, March 1987.

European Commission. 1990. Environmental Policy in the European Community. Periodical 5/1990, March 1990.

European Commission. 1990. Energy 1960-1968. Eurostat publication, 1990.

Foreign Broadcast Information Service. 1991. Daily Report Supplement - East Asia, February 27, 1991.

Grieves, C.G., Crame, L.W., Vernardos, D.G., and Ying, Wei-chi. 1980. Powdered Versus Granular Carbon for Oil Refinery Wastewater Treatment. J. Water Pollut. Control Fed., Vol. 52, No. 3. 1980. pp. 483-497.

Industrial Pollution Control Association (IPCAJ). 1983. Environmental Protection in the Industrial Sector in Japan. IPCAJ Toranomon, Minato-ku, Tokyo, 1983. p. 168.

International Environmental Reporter. 1988. Federal Republic of Germany. Jan 13, 1988, pp. 91-95.

International Environmental Reporter. 1988. English, Welsh Environmental Laws to Emphasize Integrated Pollution Control. September 1988, pp. 477-478.

International Environmental Reporter. 1988. Red List of 26 Dangerous Substances Included in Department's Consultation Paper. September 1988, pp. 478-479.

International Environmental Reporter. 1989 and 1990. The Netherlands. July 1989, pp. 385-390, and January 1990, pp. 31-33.

International Environmental Reporter. 1990. United Kingdom of Great Britain and Northern Ireland. May 1990, pp. 41-48.

Kempling, J.C. and Eng, J. 1977. Performance of Dual - Media Filters - 2. Chemical Engineering Progress. April 1977.

Klatte, E.R. 1990. The Need for Structural Changes in EC's Environmental Policy. Speech to the Center for European Policy Studies, Brussels, Jan. 19, 1990.

Langer, B.S. 1983. Wastewater Reuse and Recycle in Petroleum Refineries. Chemical Engineering Progress, May 1983, pp. 67-76.

McBride, J.S., Knecht, A.T., Bevan, S.A., and Muhlbaier, D.J. 1982. The Effect of Powdered Activated Carbon in a Petroleum Refinery Activated Sludge Treatment System. R.S. Kerr Environ. Res. Lab, U.S. EPA, Report No. EPA-600/2-82-076, 1982.

Ministry of Transport and Public Works. 1989. National Policy Document on Water Management. Water in The Netherlands: A Time for Action. Ministry of Transport and Public Works, September 1989.

Natural Resources Defense Council, Inc., vs. U.S. EPA and American Petroleum Institute, et al. 1976. U.S. Court of Appeals; Tenth Circuit, 1976.

Paris Commission. 1986. Reduction of Discharges from Refineries in the Netherlands. Paris Commission at the Tenth Meeting of the Working Group on Oil Pollution, Feb. 4-6, 1986 (dated Jan. 21, 1986).

Paris Commission. 1989. Procedures and Decisions Manual. February 1989. pp. 3-4.

Paris Commission: Procedures and Decisions Manual. 1989. Chapter on Oil: Discharges from Refineries.

Raphaelian, L. and Harrison, W. 1978. Trace Organics Variation Across the Wastewater Treatment System of a Class-B Refinery and Estimate of Removal of Refractory Organics by Add-on Mixed-Media Filtration and Granular Activated Carbon at Pilot Scales. DOE/EPA Interagency/Environment R & D Program Rept. EPA -600/7-78-125. 1978.

Rizzo, J.A. 1976. Activated Carbon Clears Effluent. Oil & Gas Journal, Vol. 74, No. 22, 1976. pp. 52-56.

Science Applications International Corporation and Amendola Engineering, Inc. 1991. Best Available Technology Options for Treatment of Chlorinated Dibenzo-P-Dioxins and Chlorinated Dibenzofurans - Ontario Petroleum Refinery Catalytic Reforming Wastewaters. Ministry of the Environment, Toronto, Ontario, (Draft) 1990.

Science Applications International Corporation, Amendola Engineering, Inc., and Apogee Research, Ltd. 1991. Status of Wastewater Generation and Treatment in Ontario Petroleum Refineries. Ministry of the Environment, Toronto, Ontario, 1991.

Stenstrom, M.K. and Grieves, C.G. 1977. Enhancement of Oil Refinery Activated Sludge by Addition of Powdered Activated Carbon. Proc. 32nd Industrial Waste Conference, Lafayette, IN. 1977. pp. 196-205.

Studies and Research Division, General Secretariat of the Economic and Social Committee, 1987. European Environmental Policy: Air, Water, Waste Management.

Thibault, G.T., Tracy, K.D., and Wilkinson, J.B. 1977. Evaluation of Powdered Activated Carbon Treatment for Improving Activated Sludge Performance. Proc. API-Refining Dept. Meeting, Chicago. 1977. pp. 235-241.

Triennial Report on Discharges from Refineries in 1987. 1989. Eleventh Meeting of the Paris Commission, Dublin, June 19-22, 1989. 17 pp.

Water General Corporation. 1983. Process Design Manual for the Stripping of Organics. EPA 68-03-3002, October 1983.

GLOSSARY

123 toxic pollutants	A U.S. EPA list of toxic pollutants used to measure the toxic levels in wastewater effluents.
4AAP	4-Amino-Anti-Pyrine, an analytical test for measuring phenolics as a class of compounds.
24-hour static bioassay test	A test procedure used to evaluate the acute lethal toxicity of refinery effluent to fish. The percent mortality of fish is observed after 24 hours.
40 CFR 419	Title 40 of the U.S. Code of Federal Regulations at Part 419.
96hr TLm static bioassay	TLm(median tolerance limit) Same as 24hr test but the percent mortality to fish is observed after the 4 day period.
Adsorption	Attraction exerted by the surface of a solid for a liquid or a gas, when they are in contact.
Advanced wastewater treatment technologies	Technologies used after secondary treatment and polishing technologies.
API	American Petroleum Institute.
BAT(EA)	Best Available Technology Economically Achievable Treatment required for industrial discharge to surface waters as defined by section 310 (b) (2) (a) of the U.S. Clean Water Act.
BBLS	Barrels of oil = 42 gallons U.S.
BIOX	Biological oxidation unit.
Blowdown	A discharge from a system, designed to prevent a buildup of some material, as in boiler and cooling tower to control dissolved solids.
BMP	Best Management Practices.

BOD	Biochemical Oxygen Demand; amount of dissolved oxygen required by aerobic microorganisms to biodegrade organic matters contained in wastewater.
BOD5	Test procedure for measuring BOD for 5 days at 20° C.
BPCTCA	Best Practicable Control Technology Currently Achievable Treatment required by July 1, 1977 for industrial discharge to surface waters as defined by section 301 (b) (1) (A) of the U.S. Clean Water Act.
BPT	Best Practicable Technology, alternate to BPCTCA.
BTX	Benzene-Toluene-Xylene mixture.
CAPDET	A computer model for estimating costs for wastewater treatment systems.
CDDs	Polychlorinated dibenzo-p-dioxins; a family of highly toxic and persistent organic chemicals.
CDFs	Polychlorinated dibenzofurans; closely related to CDD family.
Certificates of Approval	Issued by the Ontario M.O.E. for all new facilities, or changes to existing facilities, which might have an effect on the environment.
COD	Chemical Oxygen Demand; amount of oxygen equivalent of the organic matter required to complete chemical oxidation in an acidic medium.
Colloidal	Particulate matter with an approximate diameter range from 1 millimicron to 1 micron, cannot be removed by settling.
CONCAWE	The oil companies' European Organization for Environmental Health and Safety.
CT	Cooling Towers.
Cycles of concentration	The ratio of the dissolved solids concentration of the recirculating water to make-up water.

DAF	Dissolved Air Flotation units.
Direct discharger	A facility which discharges or may discharge pollutants into surface waters of Canada.
DOE	U.S. Department of Energy.
End-of-pipe treatment	Treatment of overall refinery wastes, as distinguished from treatment of wastes from individual processing units; wastewater treatment technologies that are used after gravity oil separation.
Eng News Record Index	A construction cost index published by the magazine Engineering News Record.
EPS1/PN/3	Environmental Status Report for the Canadian Petroleum Refining Industry 1987.
European Commission	Makes environmental policies which are binding to the 12 current members of the European Community based on the mutual responsibility of all European countries for their common environment.
Federal Fisheries Act	Canadian Federal Act which prohibits the deposit of deleterious substances of any type in water frequented by fish.
GAC	Granular Activated Carbon.
GALS/BBL	Gallons of processed wastewater per barrel of crude feedcharge.
IAF	Induced Air Flotation unit.
In-plant treatment	Treatment techniques that are used to reduce, reuse, recycle or treat wastewater before end-of-pipe treatment.
Incremental capital cost	The cost incurred beyond that already spent for treatment systems in-place at a facility.
Indirect discharger	A facility which discharges or may discharge pollutants into a publicly owned treatment works (sanitary sewer).

M^3	Cubic meters.
Marshal & Swift Index	An equipment cost index published by the magazine Chemical Engineering.
Mass loadings	Total amount of pollutant substance, generally expressed as pounds per day or kilograms per day; calculated by multiplying the concentration by the flowrate.
MGD	Million gallons per day.
MISA	Municipal/Industrial Strategy for Abatement.
MLSS	Mixed Liquor Suspended Solids.
MLVSS	Mixed Liquor Volatile Suspended Solids.
Non-conventional pollutants	Pollutants other than BOD, TSS, oil and grease, and the 123 toxic pollutants.
Non-contact cooling	Cooling water that does not come into direct contact with process streams.
NPDES	National Pollutant Discharge Elimination System, the U.S. wastewater permit system.
NSPS	New Source Performance Standards.
OEQO	Ontario Effluent Quality Objectives for Petroleum Refineries 1977.
Operation & maintenance (O&M) costs	Costs required to operate and maintain pollution abatement equipment. They include labor, material, and energy costs.
OTCW	Once Through Cooling Water.
Oxidant	A chemical or compound added to a solution to bring about oxidation, i.e. sulphur to sulphate.
PAC	Powdered Activated Carbon.
PAJ	Petroleum Association of Japan.

Paris Commission	The regional commission that coordinates the European treaty on land-based pollution of the North Sea.
Persistent toxic pollutants	Pollutants that either never break down or do so only very slowly.
pH	A measure of the relative acidity or alkalinity of water. A pH of 7.0 indicates a neutral condition. A greater pH indicates alkalinity and a lower pH indicates acidity. A one unit change in pH indicates a 10-fold change in acidity and alkalinity.
POTW	Publicly Owned Treatment Works.
ppq	Parts per quadrillion.
Priority pollutants	A U.S. EPA list of 129 toxic pollutants having known or suspected adverse effects upon human health or the environment.
PSNS	Pretreatment Standards for New Sources of indirect dischargers under Section 307 (b) of the U.S. Clean Water Act.
Reaction rate constant	Specific reaction rate; a constant of proportionality.
Sour water	Process wastewater which is contaminated with ammonia and hydrogen sulphide, causes bad odors.
Stripper	A unit in which certain components are removed from a liquid hydrocarbon mixture by passing a gas, usually steam through the mixture.
TDS	Total Dissolved Solids; consists of both organic and inorganic molecules and ions that are present in true solution in water.
TOC	Total Organic Carbon; the amount of carbon in the organic material in a wastewater sample.
TPI	Tilted Plate Interceptor.
Trace level	Detectable, but at a concentration less than the method detection limit.

TSS	Any solids found in wastewater or in the stream which, in most cases, can be removed by filtration. The origin of suspended matter may be man-made wastes or natural sources such as silt from erosion.
U.S. EPA	United States Environmental Protection Agency.
U.S. EPA OCPSF Study	Development Document for Effluent Limitations Guidelines and Standards for the Organic Chemicals, Plastics and Synthetic Fibers Industry, Oct. 1987.
UV	Ultraviolet.
VF	Variability Factor.
VOC	Volatile Organic Compounds; includes any organic compound (with an appreciable vapor pressure) which vaporizes when exposed to air.
VTC	Vertical Tube Coalescers.
Zero discharge	To achieve zero discharge of wastewater to receiving waters.

APPENDIX A

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TABLE 1
PROCESS WASTEWATER
TREATMENT COMPLIANCE COSTS ESTIMATES
BASIS: 1989 CANADIAN DOLLARS

		TOTAL OPTION COSTS			INCREMENTAL COSTS		
		CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES
BAT OPTION 1	MINIMUM	11,186,148	3,023,062	6.66	0	0	0
	MAXIMUM	43,918,663	8,371,898	30.36	26,789,490	4,348,960	16.09
	TOTAL	143,488,217	32,298,356	94.0	56,503,900	8,322,222	38.1
BAT OPTION 2A	MINIMUM	11,816,704	3,023,062	6.66	0	0	0
	MAXIMUM	51,062,413	9,292,648	30.36	33,933,240	5,269,710	16.09
	TOTAL	163,693,217	34,902,556	94.0	76,708,900	10,926,422	38.1
BAT OPTION 2B	MINIMUM	11,816,704	3,023,062	6.66	0	0	0
	MAXIMUM	59,691,163	10,404,798	30.36	42,561,990	6,381,860	16.09
	TOTAL	182,340,092	36,968,431	94.0	95,355,775	12,992,297	38.1
BAT OPTION 3	MINIMUM	11,816,704	3,023,062	6.66	0	0	0
	MAXIMUM	59,691,163	10,404,798	30.36	42,561,990	6,381,860	16.09
	TOTAL	182,340,092	36,968,431	94.0	95,355,775	12,992,297	38.1
BAT OPTION 4	MINIMUM	11,816,704	3,023,062	6.66	0	0	0
	MAXIMUM	59,691,163	10,404,798	30.36	42,561,990	6,381,860	16.09
	TOTAL	182,340,092	36,968,431	94.0	95,355,775	12,992,297	38.1
BAT OPTION 5A1	MINIMUM	20,710,832	4,972,078	7.66	11,080,288	1,949,016	1.08
	MAXIMUM	80,127,143	16,385,921	32.45	67,792,264	12,362,983	18.18
	TOTAL	262,114,159	56,207,241	95.10	194,388,346	32,231,106	47.00
BAT OPTION 5A2	MINIMUM	17,821,242	4,970,711	7.66	7,612,780	1,947,649	1.07
	MAXIMUM	71,140,577	15,899,744	18.66	57,876,806	11,876,806	18.12
	TOTAL	232,523,714	55,467,493	103.00	159,748,236	31,491,308	47.10
BAT OPTION 5A2 MODIFIED	MINIMUM	13,747,893	3,619,477	6.69	2,317,427	596,415	0.03
	MAXIMUM	64,079,597	11,327,591	30.41	47,829,111	7,304,653	16.14
	TOTAL	199,496,781	41,634,896	94.3	115,944,802	17,658,761	38.4
BAT OPTION 5B	MINIMUM	33,594,641	6,624,396	5.02	29,456,040	3,445,013	0.5
	MAXIMUM	134,721,863	23,621,857	14.77	149,811,724	19,598,920	0.5
	TOTAL	428,242,734	79,039,718	58.90	436,775,962	55,063,585	3.5

MINIMUM : MINIMUM OPTION COST FROM ALL SEVEN REFINERIES
MAXIMUM : MAXIMUM OPTION COST FROM ALL SEVEN REFINERIES
TOTAL : TOTAL OPTION COST FOR THE WHOLE SECTOR

TABLE 1A
PETRO-CANADA - OAKVILLE REFINERY
PROCESS WASTEWATER
TREATMENT COMPLIANCE COST ESTIMATES
BASIS: 1989 CANADIAN DOLLARS

	TOTAL OPTION COSTS (1)			INCREMENTAL COSTS (2)		
	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES
BAT OPTION 1	11,186,148	3,304,383	6.66	325,000	125,000	0.2
BAT OPTION 2A	12,547,398	3,479,833	6.66	1,686,250	300,450	0.2
BAT OPTION 2B	12,699,273	3,499,408	6.66	1,838,125	320,025	0.2
BAT OPTION 3	12,699,273	3,499,408	6.66	1,838,125	320,025	0.2
BAT OPTION 4	12,699,273	3,499,408	6.66	1,838,125	320,025	0.2
BAT OPTION 5A1	20,713,152	5,709,797	7.66	11,845,037	2,530,414	1.2
BAT OPTION 5A2	18,334,649	5,747,571	7.66	8,990,834	2,568,188	1.2
OPTION 5A2 MOD.	14,432,071	4,069,472	6.69	3,917,482	890,089	0.23
BAT OPTION 5B	33,594,641	6,624,396	6.96	29,456,040	3,445,013	0.5

(1) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, AND CONTINGENCIES COST
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST

(2) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, CONTINGENCIES, AND RETROFITTING COST
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST

TABLE 1B
PETRO-CANADA - MISSISSAUGA REFINERY
PROCESS WASTEWATER
TREATMENT COMPLIANCE COST ESTIMATES
BASIS: 1989 CANADIAN DOLLARS

	TOTAL OPTION COSTS (1)			INCREMENTAL COSTS (2)		
	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES
BAT OPTION 1	19,092,170	3,795,494	13.08	7,393,242	965,448	5.6
BAT OPTION 2A	22,410,920	4,223,244	13.08	10,711,992	1,393,198	5.6
BAT OPTION 2B	26,595,920	4,425,144	13.08	14,896,992	1,595,098	5.6
BAT OPTION 3	26,595,920	4,425,144	13.08	14,896,992	1,595,098	5.6
BAT OPTION 4	26,595,920	4,425,144	13.08	14,896,992	1,595,098	5.6
BAT OPTION 5A1	37,785,718	6,578,698	14.36	28,785,590	3,748,652	6.88
BAT OPTION 5A2	33,627,834	6,480,198	14.36	23,796,130	3,650,152	6.87
OPTION 5A2 MOD.	29,019,420	5,086,949	13.12	17,805,192	2,256,903	5.64
BAT OPTION 5C	58,956,515	10,477,876	7.98	60,769,391	7,647,830	0.5

(1) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, AND CONTINGENCIES COST
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST

(2) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, CONTINGENCIES, AND RETROFITTING COST
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST

TABLE 1C
ESSO - NANTICOKE REFINERY
PROCESS WASTEWATER
TREATMENT COMPLIANCE COST ESTIMATES
BASIS: 1989 CANADIAN DOLLARS

	TOTAL OPTION COSTS (1)			INCREMENTAL COSTS (2)		
	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES
BAT OPTION 1	11,816,704	3,023,062	8.39	0	0	0
BAT OPTION 2A	11,816,704	3,023,062	8.39	0	0	0
BAT OPTION 2B	11,816,704	3,023,062	8.39	0	0	0
BAT OPTION 3	11,816,704	3,023,062	8.39	0	0	0
BAT OPTION 4	11,816,704	3,023,062	8.39	0	0	0
BAT OPTION 5A1	20,710,832	4,972,078	9.47	11,080,288	1,949,016	1.08
BAT OPTION 5A2	17,821,242	4,970,711	9.46	7,612,780	1,947,649	1.07
OPTION 5A2 MOD.	13,747,893	3,619,477	8.42	2,317,427	596,415	0.03
BAT OPTION 5C	41,303,559	7,659,512	8.89	38,332,912	4,636,450	0.5

(1) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, AND CONTINGENCIES COST
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST

(2) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, CONTINGENCIES, AND RETROFITTING COST
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST

TABLE 1D
ESSO - SARNIA REFINERY
PROCESS WASTEWATER
TREATMENT COMPLIANCE COST ESTIMATES
BASIS: 1989 CANADIAN DOLLARS

	TOTAL OPTION COSTS (1)			INCREMENTAL COSTS (2)		
	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES
BAT OPTION 1	43,918,663	8,371,898	30.36	26,789,490	4,348,960	16.09
BAT OPTION 2A	51,062,413	9,292,648	30.36	33,933,240	5,269,710	16.09
BAT OPTION 2B	59,691,163	10,404,798	30.36	42,561,990	6,381,860	16.09
BAT OPTION 3	59,691,163	10,404,798	30.36	42,561,990	6,381,860	16.09
BAT OPTION 4	59,691,163	10,404,798	30.36	42,561,990	6,381,860	16.09
BAT OPTION 5A1	80,127,143	16,385,921	32.45	67,792,264	12,362,983	18.18
BAT OPTION 5A2	71,140,577	15,899,744	32.39	57,876,806	11,876,806	18.12
OPTION 5A2 MOD.	64,079,597	11,327,591	30.41	47,829,111	7,304,653	16.14
BAT OPTION 5C	134,721,863	23,621,857	14.77	149,811,724	19,598,920	0.5

(1) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, AND CONTINGENCIES COST
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST

(2) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, CONTINGENCIES, AND RETROFITTING COST
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST

TABLE 1E
SHELL - SARNIA REFINERY
PROCESS WASTEWATER
TREATMENT COMPLIANCE COST ESTIMATES
BASIS: 1989 CANADIAN DOLLARS

	TOTAL OPTION COSTS (1)			INCREMENTAL COSTS (2)		
	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES
BAT OPTION 1	31,798,590	7,238,752	17.26	16,821,980	2,146,527	8.56
BAT OPTION 2A	34,386,090	7,572,252	17.26	19,409,480	2,480,027	8.56
BAT OPTION 2B	35,252,340	7,683,902	17.26	20,275,730	2,591,677	8.56
BAT OPTION 3	35,252,340	7,683,902	17.26	20,275,730	2,591,677	8.56
BAT OPTION 4	35,252,340	7,683,902	17.26	20,275,730	2,591,677	8.56
BAT OPTION 5A1	47,776,330	10,316,666	10.68	35,802,115	5,224,440	9.97
BAT OPTION 5A2	42,922,106	10,164,837	18.66	29,977,047	5,072,611	9.95
OPTION 5A2 MOD.	37,946,136	8,381,609	17.30	23,508,286	3,289,383	8.6
BAT OPTION 5C	72,473,288	14,384,771	9.20	73,023,460	9,292,546	0.5

(1) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, AND CONTINGENCIES COST
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST

(2) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, CONTINGENCIES, AND RETROFITTING COST
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST

TABLE 1F
SUNCOR - SARNIA REFINERY
PROCESS WASTEWATER
TREATMENT COMPLIANCE COST ESTIMATES
BASIS: 1989 CANADIAN DOLLARS

	TOTAL OPTION COSTS (1)			INCREMENTAL COSTS (2)		
	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES
BAT OPTION 1	13,168,521	3,172,366	10.7	2,288,333	417,636	4.64
BAT OPTION 2A	16,599,771	3,614,616	10.7	5,719,583	859,886	4.64
BAT OPTION 2B	19,839,771	4,032,216	10.7	8,959,583	1,277,486	4.64
BAT OPTION 3	19,839,771	4,032,216	10.7	8,959,583	1,277,486	4.64
BAT OPTION 4	19,839,771	4,032,216	10.7	8,959,583	1,277,486	4.64
BAT OPTION 5A1	30,003,684	6,054,981	11.88	21,592,849	3,300,251	5.82
BAT OPTION 5A2	26,409,979	5,999,690	11.86	17,280,403	3,244,960	5.8
OPTION 5A2 MOD.	22,044,274	4,664,934	10.73	11,604,986	1,910,204	4.67
BAT OPTION 5C	50,516,771	9,069,998	6.56	50,841,053	6,315,268	0.5

(1) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, AND CONTINGENCIES COST
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST

(2) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, CONTINGENCIES, AND RETROFITTING COST
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST

TABLE 1G
NOVA - CORUNNA REFINERY
PROCESS WASTEWATER
TREATMENT COMPLIANCE COST ESTIMATES
BASIS: 1989 CANADIAN DOLLARS

	TOTAL OPTION COSTS (1)			INCREMENTAL COSTS (2)		
	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES
BAT OPTION 1	12,507,421	3,392,401	7.56	2,885,855	318,651	3.04
BAT OPTION 2A	14,869,921	3,696,901	7.56	5,248,355	623,151	3.04
BAT OPTION 2B	16,444,921	3,899,901	7.56	6,823,355	826,151	3.04
BAT OPTION 3	16,444,921	3,899,901	7.56	6,823,355	826,151	3.04
BAT OPTION 4	16,444,921	3,899,901	7.56	6,823,355	826,151	3.04
BAT OPTION 5A1	24,997,300	6,189,100	8.63	17,490,203	3,115,350	4.11
BAT OPTION 5A2	22,267,327	6,204,742	8.62	14,214,236	3,130,942	4.1
OPTION 5A2 MOD.	18,227,390	4,484,864	7.59	8,962,318	1,411,114	3.07
BAT OPTION 5C	36,676,097	7,201,308	5.02	34,541,382	4,127,558	0.5

(1) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, AND CONTINGENCIES COST
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST

(2) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, CONTINGENCIES, AND RETROFITTING COST
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST

TABLE 2
ONCE-THROUGH COOLING WATER
TREATMENT COMPLIANCE COSTS ESTIMATES
BASIS: 1989 CANADIAN DOLLARS

		TOTAL OPTION COSTS			INCREMENTAL COSTS		
		CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES
BAT OPTION 1	MINIMUM	UNKN	UNKN	UNKN	0	0	0
	MAXIMUM	UNKN	UNKN	UNKN	0	0	0
	TOTAL	UNKN	UNKN	UNKN	0	0	0
BAT OPTION 2	MINIMUM	0	0	0	0	0	0
	MAXIMUM	2,154,826	833,316	0.27	2,801,274	833,316	0.27
	TOTAL	6,399,274	2,615,308	0.8	8,319,055	2,615,308	0.8
BAT OPTION 3	MINIMUM	0	0	0	0	0	0
	MAXIMUM	21,168,000	448,208	4.5	21,168,000	448,208	4.5
	TOTAL	59,976,000	1,216,878	12.8	59,976,000	1,216,878	12.8

(1) - TREATMENT TECHNOLOGIES INCLUDE:
BAT OPTION 1 - EXISTING PRACTICES.
BAT OPTION 2 - DECHLORINATION, LEAK DETECTION, PLUS BMP's FOR THE CONTROL OF LEAKS AND SPILLS.
BAT OPTION 3 - 100 PERCENT AIR COOLING

MINIMUM : MINIMUM OPTION COST FROM ALL SEVEN REFINERIES
MAXIMUM : MAXIMUM OPTION COST FROM ALL SEVEN REFINERIES
TOTAL : TOTAL OPTION COST FOR THE WHOLE SECTOR

TABLE 2A
PETRO-CANADA - OAKVILLE REFINERY
ONCE-THROUGH COOLING WATER
TREATMENT COMPLIANCE COSTS (1)
BASIS: 1989 CANADIAN DOLLARS

	TOTAL OPTION COSTS (2)			INCREMENTAL COSTS (3)		
	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES
BAT OPTION 1	UNKN	UNKN	UNKN	0.0	0.0	0.0
BAT OPTION 2	0.0	0.0	0.0	0.0	0.0	0.0
BAT OPTION 3	0.0	0.0	0.0	0.0	0.0	0.0

(1) - TREATMENT TECHNOLOGIES INCLUDE:
BAT OPTION 1 - EXISTING PRACTICES.
BAT OPTION 2 - DECHLORINATION, LEAK DETECTION, PLUS
BMP's FOR THE CONTROL OF LEAKS AND SPILLS.
BAT OPTION 3 - 100 PERCENT AIR COOLING

(2) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, AND CONTINGENCIES COST
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST

(3) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, CONTINGENCIES, AND RETROFITTING COST
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST

TABLE 2B
PETRO-CANADA - MISSISSAUGA REFINERY
ONCE-THROUGH COOLING WATER
TREATMENT COMPLIANCE COSTS (1)
BASIS: 1989 CANADIAN DOLLARS

	TOTAL OPTION COSTS (2)			INCREMENTAL COSTS (3)		
	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES
BAT OPTION 1	UNKN	UNKN	UNKN	0.0	0.0	0.0
BAT OPTION 2	1,594,614	642,145	0.18	2,072,998	642,145	0.18
BAT OPTION 3	11,760,000	291,266	2.5	11,760,000	291,266	2.5

(1) - TREATMENT TECHNOLOGIES INCLUDE:
BAT OPTION 1 - EXISTING PRACTICES.
BAT OPTION 2 - DECHLORINATION, LEAK DETECTION, PLUS BMP's FOR THE CONTROL OF LEAKS AND SPILLS.
BAT OPTION 3 - 100 PERCENT AIR COOLING

(2) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, AND CONTINGENCIES COST
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST

(3) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, CONTINGENCIES, AND RETROFITTING COST
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST

TABLE 2C
ESSO - NANTICOKE REFINERY
ONCE THROUGH COOLING WATER
TREATMENT COMPLIANCE COSTS (1)
BASIS: 1989 CANADIAN DOLLARS

	TOTAL OPTION COSTS (2)			INCREMENTAL COSTS (3)		
	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES
BAT OPTION 1	UNKN	UNKN	UNKN	0.0	0.0	0.0
BAT OPTION 2	0.0	0.0	0.0	0.0	0.0	0.0
BAT OPTION 3	0.0	0.0	0.0	0.0	0.0	0.0

(1) - TREATMENT TECHNOLOGIES INCLUDE:
BAT OPTION 1 - EXISTING PRACTICES.
BAT OPTION 2 - DECHLORINATION, LEAK DETECTION, PLUS BMP's FOR THE CONTROL OF LEAKS AND SPILLS.
BAT OPTION 3 - 100 PERCENT AIR COOLING

(2) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, AND CONTINGENCIES COST
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST

(3) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, CONTINGENCIES, AND RETROFITTING COST
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST

TABLE 2D
ESSO - SARNIA REFINERY
ONCE-THROUGH COOLING WATER
TREATMENT COMPLIANCE COSTS (1)
BASIS: 1989 CANADIAN DOLLARS

	TOTAL OPTION COSTS (2)			INCREMENTAL COSTS (3)		
	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES
BAT OPTION 1	UNKN	UNKN	UNKN	0.0	0.0	0.0
BAT OPTION 2	2,154,826	833,316	0.27	2,801,274	833,316	0.27
BAT OPTION 3	21,168,000	448,208	4.5	21,168,000	448,208	4.5

(1) - TREATMENT TECHNOLOGIES INCLUDE:
BAT OPTION 1 - EXISTING PRACTICES.
BAT OPTION 2 - DECHLORINATION, LEAK DETECTION, PLUS BMP's FOR THE CONTROL OF LEAKS AND SPILLS.
BAT OPTION 3 - 100 PERCENT AIR COOLING

(2) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, AND CONTINGENCIES COST
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST

(3) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, CONTINGENCIES, AND RETROFITTING COST
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST

TABLE 2E
SHELL - SARNIA REFINERY
ONCE-THROUGH COOLING WATER
TREATMENT COMPLIANCE COSTS (1)
BASIS: 1989 CANADIAN DOLLARS

	TOTAL OPTION COSTS (2)			INCREMENTAL COSTS (3)		
	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES
BAT OPTION 1	UNKN	UNKN	UNKN	0.0	0.0	0.0
BAT OPTION 2	1,717,806	684,966	0.20	2,233,149	684,966	0.2
BAT OPTION 3	9,408,000	325,534	2.0	9,408,000	325,534	2.0

(1) - TREATMENT TECHNOLOGIES INCLUDE:
BAT OPTION 1 - EXISTING PRACTICES.
BAT OPTION 2 - DECHLORINATION, LEAK DETECTION, PLUS BMP's FOR THE CONTROL OF LEAKS AND SPILLS.
BAT OPTION 3 - 100 PERCENT AIR COOLING

(2) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, AND CONTINGENCIES COST
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST

(3) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, CONTINGENCIES, AND RETROFITTING COST
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST

TABLE 2F
SUNCOR - SARNIA REFINERY
ONCE-THROUGH COOLING WATER
TREATMENT COMPLIANCE COSTS (1)
BASIS: 1989 CANADIAN DOLLARS

	TOTAL OPTION COSTS (2)			INCREMENTAL COSTS (3)		
	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES
BAT OPTION 1	UNKN	UNKN	UNKN	0.0	0.0	0.0
BAT OPTION 2	932,028	454,881	0.1	1,211,634	454,881	0.1
BAT OPTION 3	17,640,000	151,870	3.75	17,640,000	151,870	3.75

(1) - TREATMENT TECHNOLOGIES INCLUDE:
BAT OPTION 1 - EXISTING PRACTICES.
BAT OPTION 2 - DECHLORINATION, LEAK DETECTION, PLUS BMP's FOR THE CONTROL OF LEAKS AND SPILLS.
BAT OPTION 3 - 100 PERCENT AIR COOLING

(2) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, AND CONTINGENCIES COST
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST

(3) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, CONTINGENCIES, AND RETROFITTING COST
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST

TABLE 2G
NOVA - CORUNNA REFINERY
ONCE-THROUGH COOLING WATER
TREATMENT COMPLIANCE COSTS (1)
BASIS: 1989 CANADIAN DOLLARS

	TOTAL OPTION COSTS (2)			INCREMENTAL COSTS (3)		
	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES
BAT OPTION 1	UNKN	UNKN	UNKN	0.0	0.0	0.0
BAT OPTION 2	0.0	0.0	0.0	0.0	0.0	0.0
BAT OPTION 3	0.0	0.0	0.0	0.0	0.0	0.0

(1) - TREATMENT TECHNOLOGIES INCLUDE:
BAT OPTION 1 - EXISTING PRACTICES.
BAT OPTION 2 - DECHLORINATION, LEAK DETECTION, PLUS BMP's FOR THE CONTROL OF LEAKS AND SPILLS.
BAT OPTION 3 - 100 PERCENT AIR COOLING

(2) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, AND CONTINGENCIES COST
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST

(3) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, CONTINGENCIES, AND RETROFITTING COST
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST

TABLE 3
COOLING TOWERS WATER
TREATMENT COMPLIANCE COSTS ESTIMATES
BASIS: 1989 CANADIAN DOLLARS

		TOTAL OPTION COSTS			INCREMENTAL COSTS		
		CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES	CAPITAL COST 1989 $	OPERATING COST $/YR	LAN REQU ACR
BAT OPTION 1	MINIMUM	UNKN	UNKN	UNKN	0	0	
	MAXIMUM	UNKN	UNKN	UNKN	0	0	
	TOTAL	UNKN	UNKN	UNKN	0	0	
BAT OPTION 2	MINIMUM	37,500	0	0	0	0	
	MAXIMUM	37,500	0	0	0	0	
	TOTAL	262,500	0	0	0	0	
BAT OPTION 3	MINIMUM	3,528,000	138,026	0.75	3,528,000	138,026	0.
	MAXIMUM	77,616,000	1,398,264	16.5	77,616,000	1,398,264	16
	TOTAL	182,280,000	3,089,872	38.8	182,280,000	3,089,872	38

(1) - TREATMENT TECHNOLOGIES INCLUDE:
BAT OPTION 1 - EXISTING PRACTICES.
BAT OPTION 2 - ELIMINATION OF THE USE OF TOXIC CHEMICALS IN COOLING CYCLE(S), PLUS REDUCTION IN BLOWDOWN RATE
BAT OPTION 3 - 100 PERCENT AIR COOLING

MINIMUM : MINIMUM OPTION COST FROM ALL SEVEN REFINERIES
MAXIMUM : MAXIMUM OPTION COST FROM ALL SEVEN REFINERIES
TOTAL : TOTAL OPTION COST FOR THE WHOLE SECTOR

TABLE 3A
PETRO-CANADA - OAKVILLE REFINERY
COOLING TOWERS WATER
TREATMENT COMPLIANCE COSTS (1)
BASIS: 1989 CANADIAN DOLLARS

	TOTAL OPTION COSTS (2)			INCREMENTAL COSTS (2)		
	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES
BAT OPTION 1	UNKN	UNKN	UNKN	0.0	0.0	0.0
BAT OPTION 2	37,500	0.0	0.0	0.0	0.0	0.0
BAT OPTION 3	8,232,000	216,565	1.75	8,232,000	216,565	1.75

(1) - TREATMENT TECHNOLOGIES INCLUDE:
BAT OPTION 1 - EXISTING PRACTICES.
BAT OPTION 2 - ELIMINATION OF THE USE OF TOXIC CHEMICALS IN COOLING CYCLE(S), PLUS REDUCTION IN BLOWDOWN RATE.
BAT OPTION 3 - 100 PERCENT AIR COOLING

(2) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, CONTINGENCIES AND RETROFITTING COST WHERE APPLICABLE. OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST WHERE APPLICABLE.

THE CAPITAL COST FOR BAT OPTION 2 INCLUDES STUDIES AND DESIGN TO REVISE FEED SYSTEM(S) IN ORDER TO ELIMINATE TOXIC CHEMICALS IN COOLING CYCLE(S)

TABLE 3B
PETRO-CANADA - MISSISSAUGA REFINERY
COOLING TOWERS WATER
TREATMENT COMPLIANCE COSTS (1)
BASIS: 1989 CANADIAN DOLLARS

	TOTAL OPTION COSTS (2)			INCREMENTAL COSTS (2)		
	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES
BAT OPTION 1	UNKN	UNKN	UNKN	0.0	0.0	0.0
BAT OPTION 2	37,500	0.0	0.0	0.0	0.0	0.0
BAT OPTION 3	3,528,000	344,929	0.75	3,528,000	344,929	0.75

(1) - TREATMENT TECHNOLOGIES INCLUDE:
BAT OPTION 1 - EXISTING PRACTICES.
BAT OPTION 2 - ELIMINATION OF THE USE OF TOXIC CHEMICALS IN COOLING CYCLE(S), PLUS REDUCTION IN BLOWDOWN RATE.
BAT OPTION 3 - 100 PERCENT AIR COOLING

(2) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, CONTINGENCIES AND RETROFITTING COST WHERE APPLICABLE.
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST WHERE APPLICABLE.

THE CAPITAL COST FOR BAT OPTION 2 INCLUDES STUDIES AND DESIGN TO REVISE FEED SYSTEM(S) IN ORDER TO ELIMINATE TOXIC CHEMICALS IN COOLING CYCLE(S)

TABLE 3C
ESSO - NANTICOKE REFINERY
COOLING TOWERS WATER
TREATMENT COMPLIANCE COSTS (1)
BASIS: 1989 CANADIAN DOLLARS

	TOTAL OPTION COSTS (2)			INCREMENTAL COSTS (2)		
	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES
BAT OPTION 1	UNKN	UNKN	UNKN	0.0	0.0	0.0
BAT OPTION 2	37,500	0.0	0.0	0.0	0.0	0.0
BAT OPTION 3	10,584,000	296,064	2.25	10,584,000	296,064	2.25

(1) - TREATMENT TECHNOLOGIES INCLUDE:

BAT OPTION 1 - EXISTING PRACTICES.

BAT OPTION 2 - ELIMINATION OF THE USE OF TOXIC CHEMICALS IN COOLING CYCLE(S), PLUS REDUCTION IN BLOWDOWN RATE.

BAT OPTION 3 - 100 PERCENT AIR COOLING

(2) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, CONTINGENCIES AND RETROFITTING COST WHERE APPLICABLE.
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST WHERE APPLICABLE.

THE CAPITAL COST FOR BAT OPTION 2 INCLUDES STUDIES AND DESIGN TO REVISE FEED SYSTEM(S) IN ORDER TO ELIMINATE TOXIC CHEMICALS IN COOLING CYCLE(S)

TABLE 3D
ESSO - SARNIA REFINERY
COOLING TOWERS WATER
TREATMENT COMPLIANCE COSTS (1)
BASIS: 1989 CANADIAN DOLLARS

	TOTAL OPTION COSTS (2)			INCREMENTAL COSTS (2)		
	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES
BAT OPTION 1	UNKN	UNKN	UNKN	0.0	0.0	0.0
BAT OPTION 2	37,500	0.0	0.0	0.0	0.0	0.0
BAT OPTION 3	77,616,000	138,026	16.5	77,616,000	138,026	16.5

(1) - TREATMENT TECHNOLOGIES INCLUDE:
BAT OPTION 1 - EXISTING PRACTICES.
BAT OPTION 2 - ELIMINATION OF THE USE OF TOXIC CHEMICALS IN COOLING CYCLE(S), PLUS REDUCTION IN BLOWDOWN RATE.
BAT OPTION 3 - 100 PERCENT AIR COOLING

(2) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, CONTINGENCIES AND RETROFITTING COST WHERE APPLICABLE.
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST WHERE APPLICABLE.

THE CAPITAL COST FOR BAT OPTION 2 INCLUDES STUDIES AND DESIGN TO REVISE FEED SYSTEM(S) IN ORDER TO ELIMINATE TOXIC CHEMICALS IN COOLING CYCLE(S)

TABLE 3E
SHELL - SARNIA REFINERY
COOLING TOWERS WATER
TREATMENT COMPLIANCE COSTS (1)
BASIS: 1989 CANADIAN DOLLARS

	TOTAL OPTION COSTS (2)			INCREMENTAL COSTS (2)		
	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES
BAT OPTION 1	UNKN	UNKN	UNKN	0.0	0.0	0.0
BAT OPTION 2	37,500	0.0	0.0	0.0	0.0	0.0
BAT OPTION 3	28,224,000	361,581	6.0	28,224,000	361,581	6.0

(1) - TREATMENT TECHNOLOGIES INCLUDE:
BAT OPTION 1 - EXISTING PRACTICES.
BAT OPTION 2 - ELIMINATION OF THE USE OF TOXIC CHEMICALS IN COOLING CYCLE(S), PLUS REDUCTION IN BLOWDOWN RATE.
BAT OPTION 3 - 100 PERCENT AIR COOLING

(2) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, CONTINGENCIES AND RETROFITTING COST WHERE APPLICABLE.
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST WHERE APPLICABLE.

THE CAPITAL COST FOR BAT OPTION 2 INCLUDES STUDIES AND DESIGN TO REVISE FEED SYSTEM(S) IN ORDER TO ELIMINATE TOXIC CHEMICALS IN COOLING CYCLE(S)

TABLE 3F
SUNCOR - SARNIA REFINERY
COOLING TOWERS WATER
TREATMENT COMPLIANCE COSTS (1)
BASIS: 1989 CANADIAN DOLLARS

	TOTAL OPTION COSTS (2)			INCREMENTAL COSTS (2)		
	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES
BAT OPTION 1	UNKN	UNKN	UNKN	0.0	0.0	0.0
BAT OPTION 2	37,500	0.0	0.0	0.0	0.0	0.0
BAT OPTION 3	10,584,000	334,443	2.25	10,584,000	334,443	2.25

(1) - TREATMENT TECHNOLOGIES INCLUDE:
BAT OPTION 1 - EXISTING PRACTICES.
BAT OPTION 2 - ELIMINATION OF THE USE OF TOXIC CHEMICALS IN COOLING CYCLE(S), PLUS REDUCTION IN BLOWDOWN RATE.
BAT OPTION 3 - 100 PERCENT AIR COOLING

(2) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, CONTINGENCIES AND RETROFITTING COST WHERE APPLICABLE.
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST WHERE APPLICABLE.

THE CAPITAL COST FOR BAT OPTION 2 INCLUDES STUDIES AND DESIGN TO REVISE FEED SYSTEM(S) IN ORDER TO ELIMINATE TOXIC CHEMICALS IN COOLING CYCLE(S)

TABLE 3G
NOVA - CORUNNA REFINERY
COOLING TOWERS WATER
TREATMENT COMPLIANCE COSTS (1)
BASIS: 1989 CANADIAN DOLLARS

	TOTAL OPTION COSTS (2)			INCREMENTAL COSTS (2)		
	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES
BAT OPTION 1	UNKN	UNKN	UNKN	0.0	0.0	0.0
BAT OPTION 2	37,500	0.0	0.0	0.0	0.0	0.0
BAT OPTION 3	43,512,000	1,398,264	9.25	43,512,000	1,398,264	9.25

(1) - TREATMENT TECHNOLOGIES INCLUDE:
BAT OPTION 1 - EXISTING PRACTICES.
BAT OPTION 2 - ELIMINATION OF THE USE OF TOXIC CHEMICALS IN COOLING CYCLE(S), PLUS REDUCTION IN BLOWDOWN RATE.
BAT OPTION 3 - 100 PERCENT AIR COOLING

(2) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, CONTINGENCIES AND RETROFITTING COST WHERE APPLICABLE.
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST WHERE APPLICABLE.

THE CAPITAL COST FOR BAT OPTION 2 INCLUDES STUDIES AND DESIGN TO REVISE FEED SYSTEM(S) IN ORDER TO ELIMINATE TOXIC CHEMICALS IN COOLING CYCLE(S)

TABLE 4
STORM WATER
TREATMENT COMPLIANCE COSTS (1)
BASIS: 1989 CANADIAN DOLLARS

		TOTAL OPTION COSTS			INCREMENTAL COSTS		
		CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES
BAT OPTION 1	MINIMUM	UNKN	UNKN	UNKN	0	0	0
	MAXIMUM	UNKN	UNKN	UNKN	0	0	0
	TOTAL	UNKN	UNKN	UNKN	0	0	0
BAT OPTION 2	MINIMUM	10,183,079	1,408,313	13.05	0	0	0
	MAXIMUM	33,779,729	4,671,713	43.31			
	TOTAL	158,051,394	21,814,277	202.2			

(1) - TREATMENT TECHNOLOGIES INCLUDE:
BAT OPTION 1 - EXISTING PRACTICES. TREATMENT OF STORM WATER IN IMMEDIATE PROCESS AREA.
BAT OPTION 2 - PARTIAL DIKING (PREVENT OUTSIDE WATER FROM ENTERING REFINERY'S PROPERTY)

MINIMUM : MINIMUM OPTION COST FROM ALL SEVEN REFINERIES
MAXIMUM : MAXIMUM OPTION COST FROM ALL SEVEN REFINERIES
TOTAL : TOTAL OPTION COST FOR THE WHOLE SECTOR

TABLE 4A
PETRO-CANADA - OAKVILLE REFINERY
STORM WATER
TREATMENT COMPLIANCE COSTS (1)
BASIS: 1989 CANADIAN DOLLARS

	TOTAL OPTION COSTS (2)			INCREMENTAL COSTS (2)		
	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES
BAT OPTION 1	UNKN	UNKN	UNKN	0.0	0.0	0.0
BAT OPTION 2	16,573,838	2,292,150	21.25	869,750	0.0	0.27

(1) - TREATMENT TECHNOLOGIES INCLUDE:
BAT OPTION 1 - EXISTING PRACTICES. TREATMENT OF STORM WATER IN IMMEDIATE PROCESS AREA.
BAT OPTION 2 - PARTIAL DIKING (PREVENT OUTSIDE WATER FROM ENTERING REFINERY'S PROPERTY

(2) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, CONTINGENCIES AND RETROFITTING COST WHERE APPLICABLE.
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST WHERE APPLICABLE.

INCREMENTAL COSTS INCLUDE ADDITIONAL DIKING ONLY WHERE REQUIRED.

TABLE 4B
PETRO-CANADA - MISSISSAUGA REFINERY
STORM WATER
TREATMENT COMPLIANCE COSTS (1)
BASIS: 1989 CANADIAN DOLLARS

	TOTAL OPTION COSTS (2)			INCREMENTAL COSTS (2)		
	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES
BAT OPTION 1	UNKN	UNKN	UNKN	0.0	0.0	0.0
BAT OPTION 2	24,229,075	3,350,813	31.06	0.0	0.0	0.0

(1) - TREATMENT TECHNOLOGIES INCLUDE:
BAT OPTION 1 - EXISTING PRACTICES. TREATMENT OF STORM WATER IN IMMEDIATE PROCESS AREA.
BAT OPTION 2 - PARTIAL DIKING (PREVENT OUTSIDE WATER FROM ENTERING REFINERY'S PROPERTY).

(2) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, CONTINGENCIES AND RETROFITTING COST WHERE APPLICABLE.
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST WHERE APPLICABLE.

INCREMENTAL COSTS INCLUDE THE ADDITIONAL DIKING REQUIRED ONLY.

TABLE 4C
ESSO - NANTICOKE REFINERY
STORM WATER
TREATMENT COMPLIANCE COSTS (1)
BASIS: 1989 CANADIAN DOLLARS

	TOTAL OPTION COSTS (2)			INCREMENTAL COSTS (2)		
	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES
BAT OPTION 1	UNKN	UNKN	UNKN	0.0	0.0	0.0
BAT OPTION 2	31,602,656	4,370,625	40.50	0.0	0.0	0.0

(1) - TREATMENT TECHNOLOGIES INCLUDE:
BAT OPTION 1 - EXISTING PRACTICES. TREATMENT OF STORM WATER IN IMMEDIATE PROCESS AREA.
BAT OPTION 2 - PARTIAL DIKING (PREVENT OUTSIDE WATER FROM ENTERING REFINERY'S PROPERTY)

(2) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, CONTINGENCIES AND-RETROFITTING COST WHERE APPLICABLE.
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST WHERE APPLICABLE.

INCREMENTAL COSTS INCLUDE ADDITIONAL DIKING ONLY WHERE REQUIRED.

TABLE 4D
ESSO - SARNIA REFINERY
STORM WATER
TREATMENT COMPLIANCE COSTS (1)
BASIS: 1989 CANADIAN DOLLARS

	TOTAL OPTION COSTS (2)			INCREMENTAL COSTS (2)		
	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES
BAT OPTION 1	UNKN	UNKN	UNKN	0.0	0.0	0.0
BAT OPTION 2	10,183,079	1,408,313	13.05		0.0	

(1) - TREATMENT TECHNOLOGIES INCLUDE:
BAT OPTION 1 - EXISTING PRACTICES. TREATMENT OF STORM WATER IN IMMEDIATE PROCESS AREA.
BAT OPTION 2 - PARTIAL DIKING (PREVENT OUTSIDE WATER FROM ENTERING REFINERY'S PROPERTY)

(2) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, CONTINGENCIES AND RETROFITTING COST WHERE APPLICABLE.
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST WHERE APPLICABLE.

INCREMENTAL COSTS INCLUDE ADDITIONAL DIKING ONLY WHERE REQUIRED.

TABLE 4E
SHELL - SARNIA REFINERY
STORM WATER
TREATMENT COMPLIANCE COSTS (1)
BASIS: 1989 CANADIAN DOLLARS

	TOTAL OPTION COSTS (2)			INCREMENTAL COSTS (2)		
	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES
BAT OPTION 1	UNKN	UNKN	UNKN	0.0	0.0	0.0
BAT OPTION 2	33,779,729	4,671,713	43.31	0.0	0.0	0.0

(1) - TREATMENT TECHNOLOGIES INCLUDE:
BAT OPTION 1 - EXISTING PRACTICES. TREATMENT OF STORM WATER IN IMMEDIATE PROCESS
BAT OPTION 2 - PARTIAL DIKING (PREVENT OUTSIDE WATER FROM ENTERING REFINERY'S PR

(2) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, CONTINGENCIES AND RETROFITTING COST WHERE APPLICABLE.
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST WHERE APPLICABLE.

INCREMENTAL COSTS INCLUDE ADDITIONAL DIKING ONLY WHERE REQUIRED.

TABLE 4F
SUNCOR - SARNIA REFINERY
STORM WATER
TREATMENT COMPLIANCE COSTS (1)
BASIS: 1989 CANADIAN DOLLARS

	TOTAL OPTION COSTS (2)			INCREMENTAL COSTS (2)		
	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES
BAT OPTION 1	UNKN	UNKN	UNKN	0.0	0.0	0.0
BAT OPTION 2	20,614,579	2,806,913	26.01	0.0	0.0	0.0

(1) - TREATMENT TECHNOLOGIES INCLUDE:
BAT OPTION 1 - EXISTING PRACTICES. TREATMENT OF STORM WATER IN IMMEDIATE PROCESS AREA
BAT OPTION 2 - PARTIAL DIKING (PREVENT OUTSIDE WATER FROM ENTERING REFINERY'S PROPERT

(2) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, CONTINGENCIES AND RETROFITTING COST WHERE APPLICABLE.
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST WHERE APPLICABLE.

INCREMENTAL COSTS INCLUDE ADDITIONAL DIKING ONLY WHERE REQUIRED.

TABLE 4G
NOVA - CORUNNA REFINERY
STORM WATER
TREATMENT COMPLIANCE COSTS (1)
BASIS: 1989 CANADIAN DOLLARS

	TOTAL OPTION COSTS (2)			INCREMENTAL COSTS (2)		
	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES	CAPITAL COST 1989 $	OPERATING COST $/YR	LAND REQUIR. ACRES
BAT OPTION 1	UNKN	UNKN	UNKN	0.0	0.0	0.0
BAT OPTION 2	21,068,438	2,913,750	27.0		0.0	

(1) - TREATMENT TECHNOLOGIES INCLUDE:
BAT OPTION 1 - EXISTING PRACTICES. TREATMENT OF STORM WATER IN IMMEDIATE PROCESS AREA.
BAT OPTION 2 - PARTIAL DIKING (PREVENT OUTSIDE WATER FROM ENTERING REFINERY'S PROPERTY

(2) - CAPITAL COST INCLUDES EQUIPMENT, INSTALLATION, DESIGN, ENGINEERING, CONTINGENCIES AND RETROFITTING COST WHERE APPLICABLE.
OPERATING COST INCLUDES OPERATING AND MAINTENANCE LABOR, POWER, MATERIAL, CHEMICAL AND ADMINISTRATIVE COST WHERE APPLICABLE.

INCREMENTAL COSTS INCLUDE ADDITIONAL DIKING ONLY WHERE REQUIRED.

PART II

STATUS OF WASTEWATER GENERATION AND TREATMENT IN ONTARIO PETROLEUM REFINERIES

FOR

THE MISA PETROLEUM REFINING SECTOR
JOINT TECHNICAL COMMITTEE

BY

SCIENCE APPLICATIONS INTERNATIONAL CORPORATION
IN ASSOCIATION WITH
AMENDOLA ENGINEERING INC.
APOGEE RESEARCH INTERNATIONAL LTD.

JULY 1992

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5.0-11.0 CURRENT STATUS OF INDIVIDUAL REFINERIES

These sections contain individual status reports for each of the 7 refineries in Ontario.

Section 5.0 Esso Sarnia
6.0 Nova Petrochemicals Corunna
7.0 Shell Sarnia
8.0 Suncor Sarnia
9.0 Esso Nanticoke
10.0 Petro Canada Oakville
11.0 Petro Canada Mississauga

These sections are subdivided as follows using Esso Sarnia as an example.

5.1 Plant Description
  5.1.1 Refinery Process Data
5.2 Feedstocks Run in 1989
5.3 Chemicals Used see Section 5.15
5.4 Water Management
  5.4.1 Water Supply
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5.10 Fundamental Factors Affecting Effluent Quality
5.11 Control Orders Issued
5.12 Capital and Annual Operating Costs for Wastewater Treatment System
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  - Process Flow Schematic
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APPENDIX Questionaire

ABSTRACT

In 1989 the Ontario Ministry of the Environment initiated the Municipal-Industrial Strategy for Abatement (MISA) Program to strengthen the control of water pollution. The ultimate goal of the MISA program is the "virtual elimination" of persistent toxic contaminants from all discharges into Ontario's waterways.

This report documents the current status of plant operations and wastewater treatment systems at Ontario's 7 petroleum refineries. The report is intended to provide a handy reference for the Joint Technical Committee of the Petroleum Refining Sector as they undertake the setting of new limitations on persistent and conventional pollutant discharges.

The information in the report has been extracted from data supplied by the refineries to the consultants, the MISA monitoring files and the operations files of the Ministry of the Environment. These refinery reports have been verified by the refinery personnel for technical accuracy.

Project Team

This report was prepared by Apogee Research International Ltd. The work was done under the direction of Warren J. Grant, P.Eng assisted by Carolyn Caine of Apogee Research, Susan Christian of SAIC and Gary Amendola of Amendola Engineering.

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1.0 EXECUTIVE SUMMARY

In 1974 Environment Canada issued Petroleum Refinery Effluent Regulations and Guidelines in an effort to regulate fairly all refineries in Canada regardless of size, location or complexity. This was the first attempt to establish a uniform minimum standard across Canada and a very significant reduction in pollutants resulted. Since that time most of the provinces have issued their own regulations or objectives based on concentration limits.

In 1986 Ontario went another step further with the initiation of the Municipal-Industrial Strategy for Abatement (MISA) program. The intention of this program is to further regulate 9 industrial sectors plus municipal treatment plants based on the Best Available Technology with the goal of "virtual elimination" of persistent toxic chemicals into the Great Lake system. The petroleum refinery sector with 7 plants in Ontario is the first to be selected for study and further regulation.

This report summarizes the status of the 7 refineries in 1989 coinciding with the in-depth sampling and testing program carried out in that year. Together with other economic and technical studies being undertaken under the same contract the Joint Technical Committee of the Petroleum Refining Sector can use this information as a resource document in assessing the feasibility and cost of further regulations towards BAT levels of control.

Only 3 of the 7 plants can be considered as conventional refineries in the strictest sense. Nova Petrochemicals produces feedstocks for the nearby petrochemical industries while Petro Canada's Mississauga Refinery processes sufficient crude oil to produce lubricating oils and grease to meet demand. Both of these plants market a very limited number of conventional petroleum products. Both Shell Canada and Esso Petroleum in Sarnia produce an extensive list of petrochemicals going well beyond the production of benzene, toluene and xylene. The latter are normally considered as conventional refinery products according to the definition of a refinery as established by Environment Canada in Petroleum Refinery Effluent Regulations and Guidelines in 1974. Both Shell Canada and Esso Petroleum in Sarnia employ integrated wastewater treatment plants for refinery and petrochemical production.

Cooling methods vary considerably from plant to plant. Nova Petrochemicals is completely cooled by recirculated cooling water while Esso Nanticoke is 85% air cooled. Between these extremes the remaining 5 plants employ mixtures of once through cooling water, air cooling and recirculated water. Recent trends are towards maximum use of air cooling but it may take some time to make this change. Organo phosphates have replaced zinc chromium compounds at 4 plants for recirculated water systems. The remaining three Shell Sarnia, Petro Canada's two plants at Oakville and Mississauga still used zinc chromate chemicals during 1989.

The ratio of process wastewater to feedstock varies from plant to plant. Without any changes 3 of the 7 plants have ratios close to that established by EPA's BAT regulations. The others are higher even after allowing for chemical plant contributions from two of them.

A number of methods for recycling and reusing water within the plants are already in use. The use of stripped sour water for desalter make up, the recycling of steam condensate, the recycling of pump and compressor gland water and the minimization of cooling tower blow down are all employed. The report identifies selected sources of wastewater in each plant and recommends approaches for reduction. Significant reductions can only be made after thorough in plant studies have been done.

The 7 plants all use modern wastewater treatment methods. Storm water is segregated in all cases but not always in the same way. Ballast water in all cases receives full biological treatment. The process wastewater is treated along conventional lines. API separators, air flotation or dual media filters followed by equalization basins, biological treatment and clarification before discharge are the usual methods. Final dual media filtration of the effluent plus ponding is practiced in one plant while one other refinery uses granular activated carbon mainly for periods when the storm water system is overloaded. On occasion the filters are used to treat process effluent.

Compared with Ontario objectives for refineries compliance was good in 1989. Suspended solids was the major source of non compliance. Colloidal clay particles from surface run off seems to be the main source. Most of the plants would probably need some modifications to meet EPA's BAT regulations

The greatest improvement has come from the internal management systems set up over the last few years. All of the plants treat wastewater treatment as a process with its own specification to be met. Responsibility and authority has been clearly spelled out. Operators will be attending a one week course of instruction at Lambton College in 1991 using an excellent manual developed by PACE and the Ontario Petroleum Association (now CPPI). Environmental personnel are routinely involved at the very earliest stages of a project.

In 1989, 38 liquid spills were reported by the 7 refineries to the Ministry of the Environment. Regardless of size every spill must be reported so some judgement enters into the reporting process. The larger spills occurred inside of the refineries but there were some small spills around the docks. In all cases these were cleaned up promptly. Some plants have initiated programs to reduce frequency and severity through training, increased vigilance and risk analysis.

2.0 REFERENCES AND GLOSSARY OF TERMS

References

Ontario Ministry of the Environment

MISA Reports

- Effluent Monitoring Regulations for the Petroleum Refining Sector July 1988
- Preliminary Report for the First Six Months of Monitoring in the Petroleum Refining Sector December 1989
- Second Report on the Monitoring Data for the Petroleum Refining Sector July 1990

Environment Canada

- Environmental Status Report for the Canadian Petroleum Refining Industry 1987. Report EPS1/PN/3 July 1990
- Petroleum Refining Effluent Regulations and Guidelines Report EPS1-WP-74-1 January 1974

Canadian Petroleum Products Institute (CPPI) (Ontario Region)

- Canadian Petroleum Refineries Atmospheric Emission
  Survey No. 85-1 November 1985
- A Summary of the U.S. Experience in Developing BAT Limits for Petroleum Refineries No. 89-2 May 1989
- Refinery Wastewater Treatment Plant Operations Training Manual September 1989
- MISA Monitoring Results for Ontario Petroleum Refineries July 1990

Glossary of Terms - Report used terms in left column

Process Units	**Name Commonly Used**
Alkylation Unit	Alky Unit
Catalytic Reforming Unit	C.R.U. Powerformer Unit Platformer Unit Hydrobon Unit Reformer Unit
Crude Unit	Atmospheric Unit
Vacuum Unit	V.S.U. (Vacuum Stilling Unit)
Fluid Catalytic Cracker Unit	FCCU FCC Unit
Hydrogen Desulphurization Unit	H.D.S. Hydrofiner Unit
Sulphur Recovery Unit	S.R.U.
Hydrogen Plant	Hydrogen Synthesis Plant
Polymerization Unit	Poly Unit
Isomerization Unit	Isomax Unit
Distillate Desulphurizer Unit	DDS Unit
Products	
Liquid Petroleum Gas	L.P.G. (includes propane, butane, butene, butylene)
Catalytic Cracker Feed	Cat. Cracker Feed
Polymerization Gasoline	Poly gasoline
Vacuum Gas Oil	V.G.O.
Light Cycle Gas Oil	L.C.G.O. Light Cycle Stock

Heavy Cycle Gas Oil	H.C.G.O. Heavy Cycle Stock Decant Oil
Light Straight Run Distillate	Stove Oil Kerosene No.1 Fuel Oil
Light Straight Run Gasoline	L.S.R. Gasoline Virgin Gasoline Straight Run Naphtha
Light Cat Cracked Gasoline	L.C.N. (Light Cracked Naphtha) Light Naphtha
Heavy Cat Cracked Gasoline	H.C.N. (Heavy Cracked Naphtha) Heavy Naphtha
Bunker Fuel	Heavy Fuel Oil L.R.F. (Liquid Refinery Fuel) Residual Fuel No. 6 Fuel Oil Bunker C (a special grade of No.6)
Furnace Oil	No. 2 Fuel Oil Domestic Fuel Distillate Heating Oil

Wastewater

Once Through Cooling Water	OTCW
Process Wastewater	Oily Water Oil Contacted Water
Recirculated Cooling Water	Treated CW
Domestic Water	Municipal Water Potable Water
Storm Water	Potentially Contaminated Surface Runoff

Uncontaminated Storm Water	Clean Run Off
Sour Water	Foul Water Foul Condensate Sour Condensate
Sanitary Waste	Municipal Sewage Domestic Sewage
Slop Tanks	Wet Oil Tanks
Dissolved Air Flotation	DAF
Induced Air Flotation	IAF
Tilted Plate Interceptor	TPI CPI (corrugated plate)
Outfall	Plant Effluent End of Pipe
Final Holding Pond	Surge Lagoon
Mixed Liquor Suspended Solids	MLSS
Mixed Liquor Volatile Suspended Solids	MLVSS
Landfarm	Biodegradation site Sludge Farm
Long Tons/Day	LTD
Organizations	
Canadian Petroleum Products Institute	CPPI
Petroleum Association for Conservation of the Canadian Environment (now part of CPPI)	PACE
Ontario Petroleum Association (now part of CPPI)	OPA
U.S. Environmental Protection Agency	U.S. EPA

Miscellaneous

Canadian Gallons per minute	Canadian GPM
U.S. Gallons per minute	U.S. GPM
Ontario Effluent Quality Objective	OEQO
Best Available Technology	B.A.T.
Best Practicable Technology	B.P.T.

3.0 INTRODUCTION

3.1 Objectives

In August 1990 the Ontario Ministry of the Environment under the MISA program engaged SAIC and Apogee Research International to undertake the following studies.

1. A report on the current status of the 7 Ontario petroleum refineries.
2. The current status of comparable Canadian refineries outside of Ontario.
3. Performance assessment of technologies used in Ontario.
4. Evaluation and recommendations of potential B.A.T. (Best Available Technology) for Ontario, Canada, U.S.A., Europe and Japan.
5. An estimate of the costs involved in implementing the various recommended BAT options at the Ontario refineries.

3.2 Scope of this Report

This report covers the performance of the Ontario refineries. The report may be used as a basic source of information by the Joint Technical Committee in the application of Best Available Technology to the treatment of wastewaters in Ontario refineries.

The remaining scope of the project will be covered by subsequent reports.

3.3 Methodology

A lengthy questionnaire was sent to each of the refineries in advance of a one day site visit. During the plant visit the wastewater treatment plant was carefully inspected and personnel questioned. Following the plant visit a joint meeting of several plant personnel and the consultants was held to clarify points raised about the questionnaire and to complete a set of Best Management Practices (BMP's) forms. These were filled in by the consultants as the conversation progressed. The BMP's were intended to highlight a number of refinery practices which impact on the performance of the wastewater treatment system.

A copy of the questionnaire will be found at the end of this section.

On return to the consultant the questionnaires were checked for completeness and missing data requested. Data which appeared to be in error was questioned and this led to many changes. This process was very time consuming but necessary for the purpose of this report.

The following schedule of visits was followed:

Nova Petrochemicals, Corunna, September 6, 1990.

M.O.E.	Tony Powell	Nova	Bruce Martin
	Tim Little		Ted Kierstead
Apogee	Carolyn Caine		Stacy Symington
	Warren Grant		Rick Beleutz

Suncor Inc., Sarnia, September 7, 1990.

M.O.E.	Tony Powell	Suncor	Jim Greenshields
	Tim Little		Tom Brown
Apogee	Carolyn Caine		John Pyburn
	Warren Grant		

Petro Canada, Oakville, September 11, 1990.

M.O.E.	Nada Thornton	Petro Canada	John Ferris
	Richard Gibson		Roger Cousens
Apogee	Carolyn Caine		
	Warren Grant		
SAIC	Barry Langer		
	Susan Christians		

Esso, Sarnia, September 13, 1990.

M.O.E.	Tim Little	Esso	Peter Forristal
	Shawn Michajluk		Mark Psutka
Apogee	Carolyn Caine		Kevin McKinley
	Warren Grant		Jim Maness
			Mike Foley

Shell, Sarnia, September 14, 1990.

M.O.E.	Tim Little	Shell	Dana Atwell
	Shawn Michajluk		Ed Brost
Apogee	Carolyn Caine		
	Warren Grant		

Petro Canada, Mississauga, September 17, 1990.

M.O.E.	Paul Gratzer	Petro Canada	Roger Cousens
SAIC	Susan Christians		Robert Dupuis
Apogee	Warren Grant		

Esso, Nanticoke, September 21, 1990.

M.O.E.	Paul Gratzer	Esso	Ron Cameron
	Bruce Creamer		Geoff Goulding
	Peter Syring		Tom Hewitt
S.A.I.C.	Steve Stavrou	Amendola	Gary Amendola
			Jim Parker

4.0 OVERVIEW OF THE STATUS OF THE SEVEN REFINERIES

4.1 Federal Legislation

Sections 33 and 34 of the Federal Fisheries Act prohibit the deposition of "deleterious substances" into any waters in Canada frequented by fish. Under these sections of the Fisheries Act, Environment Canada in consultation with the petroleum industry issued "Petroleum Refinery Effluent Regulations and Guidelines in January, 1974." The regulations apply to all new refineries built since that time while the guidelines set performance standards for refineries then in operation. All crude capacity added since 1974 comes under the provisions of the regulations which are twice as stringent as the guidelines. The limits were expressed in kg/day.

The regulations and guidelines were based on the best practicable technology then in use. They were intended to ensure a minimum standard of performance across the country and to eliminate "pollution havens". Even though guidelines are not enforceable in law the industry responded by upgrading existing facilities to bring them into line with the guidelines. In Ontario state of the art biological treatment systems resulted in a very significant reduction in the conventional pollutants controlled under the regulations and guidelines. These pollutants are oil and grease, phenols, suspended solids, sulphides, ammonia and pH. In addition each plant runs a monthly fish toxicity test using Rainbow Trout to ensure that the wastewater is not acutely toxic. The results achieved in Ontario during the period 1972 to 1987 show very clearly in Environment Canada's "Environment Status Report for the Canadian Petroleum Refinery Industry 1987", Report EPS:/PN/3 July 1990.

4.2 Provincial Legislation

In addition to the basic requirements of the Federal legislation Ontario, Quebec, Alberta and British Columbia have superimposed additional requirements. The Ontario requirements specify a concentration limit whereas the federal legislation is based on loadings for each pollutant (Kg per day).

TABLE I
Ontario Effluent Quality Objectives for Refineries

SUBSTANCE	MONTHLY AVERAGE CONCENTRATION mg/L
Oil and Grease	10
Phenols	0.020
Suspended Solids	15
Ammonia Nitrogen	10
Chemical Oxygen Demand	200
Chromium	1
Copper	1
Nickel	1
Lead	1
Zinc	1
pH	5.5 - 9.5
Toxicity	No more than 50% fish mortality for process effluent, once through cooling water, and treated stormwater

The Objectives do not have the force of law but they serve as a guideline to the MOE abatement staff in issuing Certificates of Approval.

4.3 Certificates of Approval and Control Orders

Unlike the other provinces which use a permit system, Ontario M.O.E. issues a Certificate of Approval for all new or changed facilities which might have an effect on the environment. This certificate must be issued before construction commences.

The applicant submits technical documentation to show that the proposed changes will not result in contravention of the Environment Protection Act and its regulations. If the documentation is found to be satisfactory, a Certificate of Approval is issued usually with certain conditions attached. If a test run is specified the applicant is required to carry this out within a specified time and to correct any short comings in the predicted results.

A Control Order is issued under the signature of the Minister of the Environment and can be used to order a company to take any reasonable measures to correct an existing situation. Provision is made to contest or modify the terms of the order before it comes into effect, but failure to do so renders the Control Order enforceable in the courts.

None of the Ontario refineries had outstanding Control Orders in 1989.

4.4 Capital Costs 1970-1989

The Federal Regulations and Guidelines passed in 1974 plus the Ontario Effluent Quality Objectives in 1976 resulted in large scale upgrading of treatment facilities. As a result all plants now have treatment systems incorporating full biological treatment of the process wastewater. Biological treatment has the ability to remove organics and to reduce toxicity.

The following information was provided by the refineries for the cost of wastewater treatment equipment expressed in 1989 dollars.

TABLE II
Capital Costs 1970-1989

REFINERY	$ MILLIONS CAPITAL COST
Esso Sarnia	90
Shell Sarnia	47
Suncor Sarnia	10
Nova Petrochemicals Corunna	30
Petro Canada Mississauga	17.6
Petro Canada Oakville	25
Esso Nanticoke	91.0*
TOTAL	310.6

* Includes cost of new plant facilities.

4.5 Annual Operating Costs

Normally refineries do not keep separate accounting records for the operating costs associated with wastewater treatment. Three companies however were able to provide some estimates. Esso Sarnia reported $2.7 million in 1989, Esso Nanticoke reported $2.5 million and Nova reported $2.4 million. Since the other plants employ somewhat similar treatment modules it would be reasonable to assume similar costs for labour, chemicals, utilities and maintenance prorated to their wastewater flow. These operating costs do not take into account depreciation of capital investment. Depreciation is generally considered to be between 10 and 20% per year of capital cost.

4.6 Industry Trends Contributing to the Emission of Pollutants

A number of industry trends have contributed to the reduction of pollutants over the last few years.

The use of zinc-chromate compounds to control corrosion in cooling towers has been largely replaced. Only Shell Sarnia, Petro Canada Mississauga and Petro Canada Oakville used such preparations in 1989. The latter refinery discontinued their use in 1990 while Petro Canada Mississauga plans to change over in mid

1991. Betz Chemicals has taken these chromate-zinc compounds off the market as a matter of environmental policy.

Table III compares the feedstocks processed in 1983 and 1989.

TABLE III
FEEDSTOCKS PROCESSED
1983 & 1989

REFINERY	1983 M^3/C.D.	BPCD	1989 M^3/C.D.	BPCD
Esso Sarnia	14668	(92408)	17976	(113069)
Shell Sarnia*	8541	(53808)	10400	(65416)
Suncor Sarnia	12435	(78340)	11076	(69668)
Nova Corunna**	8874	(55906)	11405	(71737)
Petro Canada Oakville	10159	(64003)	10605	(66705)
Petro Canada Mississauga	8328	(52466)	6653	(41847)
Esso Nanticoke	14614	(92069)	18360	(115484)
TOTAL	77619	(489000)	86475	(543926)

NOTE: BPCD (barrels per calendar day)

* Shell Sarnia feedstock for 1989 includes crude oil plus 630 m^3/day of feed to the chemical plant.

** In addition to the conventional crude/condensates Nova purchased 4055 M^3/C.D. of light petroleum fractions in 1989 and all of these were thermally cracked with exception of some light oils.

Net increase is 11.4% since 1983 or 1.9% per year. Part of the increase is probably due to the closure of 4 of the 7 refineries in Quebec during this period.

Acute toxicity to Rainbow Trout has been almost completely eliminated as a problem over the last 15 years due to improved treatment methods. Much of this improvement has been due to the adoption of biological treatment as a standard method of treatment for toxic waste streams in the Ontario Refineries. During 1989 6 of the 7 refineries exhibited no acute toxicity to Rainbow Trout as measured by a monthly test. Petro Canada Oakville effluent was acutely toxic on three occasions to both Rainbow Trout and Daphnia Magna. The acute toxicity is believed to have been due to excessively high zinc and chromate levels in the wastewater.

During the last 10 years reliable instruments have become available for controlling the treatment processes as well as for the continuous monitoring of key parameters. One refinery has taken advantage of these new developments and will shortly institute feed forward control. This consists of controlling an upstream variable as soon as the slightest deviation is detected downstream.

One of the most notable improvements has been the training of wastewater treatment operators. Many of the problems in the past were traced to a lack of understanding by the operators of complex equipment. The plants recognize this need and have instituted various types of training programs for upgrading of skills. CPPI have developed a training manual for treatment operators. In the Spring of 1991 Lambton College will present a one week course using this manual as a basic text. All plant operators are expected to attend on a rotational basis. Some USA refineries have requested copies of the manual.

In anticipation of tighter controls which may be required under the MISA program several plants have instituted studies to reduce water use and thereby improve treatment efficiency.

All of the refineries have some kind of storm water management in place. Run off from the process area pads goes directly to the process effluent sewer in all of the plants except Petro Canada Mississauga. In the latter plant only storm water falling in the older process units goes to the process effluent sewer directly. In the new sections the storm water goes to a collection pond and is then treated biologically at a controlled flow. Three refineries (Esso Sarnia, Suncor Sarnia and Petro Canada Mississauga) treat all of the storm water collected on the property. The remaining 4 plants have different levels of storm water segregations. In Esso Nanticoke, Nova Petrochemicals Corunna and Shell Sarnia the uncontaminated storm water is segregated from the contaminated water and is collected in a pond, tested and if satisfactory released. If it does not meet required quality, the water is routed through the biological treatment system before release. In Petro Canada Oakville storm water is biologically treated only to the extent possible. Excess storm water is de-oiled and sent to the final effluent lagoon before discharge.

4.7 Summary of Comparative Data

4.7.1 Purpose of the Plants

Table IV shows the great diversity of purpose among the 7 plants.

TABLE IV

REFINERY	PURPOSE OF PLANT
Esso Sarnia	Petroleum and chemical products, lube oils
Shell Sarnia	Petroleum and chemical products
Suncor Sarnia	Petroleum products
Nova Corunna	Limited petroleum products, emphasis on chemical feedstocks
Petro Canada Oakville	Petroleum products
Petro Canada Mississauga	Some petroleum products but mainly lube oils
Esso Nanticoke	Petroleum products

Of the above 7 plants only 3 are conventional petroleum refineries producing a full slate of saleable petroleum products, 2 have a large petro chemicals component, one exists mainly for the production of lubricating oils while one is basically a petro chemicals feed preparation plant using not only crude oil but purchased feedstocks from local plants for processing in the Thermal Cracking Unit.

4.7.2 Cooling Methods Used

Table V below shows an estimate of the total process heat load removed by OTCW (once through cooling water), C.T. (cooling towers) and Air Cooling.

TABLE V

REFINERY	TYPE OF COOLING %		
	OTCW	CT	AIR
Esso Sarnia	75	20	5
Shell Sarnia*	75	0	25
Suncor Sarnia	35	60	5
Nova Corunna	0	100	0
Petro-Canada Oakville	0	50	50
Petro-Canada Mississauga	22	69	9
Esso Nanticoke	0	15	85

* The Chemical Plant uses 100% recirculated water

Current practice in the newer refineries is to use a combination of recirculated water (cooling towers) and air cooling with the trend towards more air cooling. Each of these systems has disadvantages from an environmental stand point as shown by the following data in Table VI.

TABLE VI
Advantages and Disadvantages of Various Types of Cooling Systems

	OTCW	COOLING TOWERS	AIR
Noise problems	none	usually low	can be high
Cold weather plumes	none	may be a problem	none
Danger of water contamination	yes	moderate	none
Danger of air contamination	none	yes	yes
Cooling efficiency	excellent	good	may be low
Energy required	moderate	high	high
Maintenance and labour	low	high	low
Impact of treatment chemicals*	some	yes	none

* Shock treatment with high levels of chlorine for control of Zebra Mussels is becoming common. This requires addition of a scavenger such as sodium metabisulphite to the discharged water to remove chlorine down to acceptable levels.

4.7.3 Process Wastewater per Barrel of Feedstock

The ratio of wastewater to feedstock appears in more detail in the individual refinery reports. Table VII, on the following page, compares the actual process wastewater reported in the MISA program with the US EPA B.A.T. flow which would be used in calculating loadings.

Table VII shows that 4 of the 7 refineries produce less wastewater per barrel of feedstock than the amount used for calculations under BPT. The remaining refineries exceed the calculated allowance.

Only 3 of the 7 refineries would produce less wastewater than the allowance under BAT. A fourth refinery is very close to the BAT.

EPA excludes petrochemicals production in calculating the US gallons per barrel of feed. In Canada the definition of a refinery includes BTX production. In addition process effluent in most cases includes varying amounts of storm run off and ballast water while in the USA extra allowances are generally made for these flows.

TABLE VII
Process Wastewater
EPA BPT/BAT Flows versus MISA Actual Flows
All flows expressed in U.S. gallons per barrel of feed

Refinery	EPA Complexity Category	Flow U.S. Gal/BBL			Flow Ratio	
		MISA Actual	EPA		MISA / BPT	MISA / BAT
			BPT	BAT		
Esso (Sarnia)	D	66	72	46	0.92	1.43
Shell (Sarnia)	C	54	27	24	2.00	2.25
Suncor (Sarnia)	C	34	32	33	1.06	1.03
Novacor (Corunna)	C	21	32	29	0.69	0.74
Petro Canada (Oakville)	B	19	28	21	0.68	0.90
Petro Canada (Mississauga)	D	69	58	44	1.19	1.57
Esso (Nanticoke)	B	15	31	24	0.48	0.63

* This ratio based upon crude throughput only - not total feedstock as shown in Table III.

4.7.4 Selected Sources of Process Wastewater

Table VIII shows a number of sources of process wastewater. These sources have been selected because they represent areas where wastewater might be reduced. These sources do not add up to the total MISA flow shown in the left column because there are undisclosed sources of wastewater. Only on in depth study of all sources could approximate a mass balance.

TABLE VIII
SELECTED SOURCES OF WASTE WATERS - M^3/day

Plant	MISA Flow M^3/day	SOURCE									
		Sour Water Stripper	Ballast Water	Cooling Tower Blowdown	Pumps Compressors	Boiler B.D.	Storm	Water Treat.	Desalter	Land farm	Cat Reformer Scrubber Liquid
Esso Sarnia	28189	1750	174	1090	370	324	1800	N/A	1145	N/A	$10M^{3/m}$
Shell Sarnia	13292	650		400 (Chem Plt)	1500	600	150	250	483	N/A	$2000M^3$/yr caustic $26000M^3$/yr wash water
Suncor Sarnia	8991	470	275	300	1152	5	N/A	N/A	625	N/A	$130M^3$/yr
Nova Corunna	5832	869	N/A	1800	NIL	N/A	N/A	N/A	845	N/A	No Reformer
Petro Oak.	4844	637	35	460	200	350	250	240	530	N/A	161 M^3/yr
Petro Miss.	10917	438	33	485	572 2469 to OTCW	365	2420	N/A	500	N/A	NIL - Use Cont Regen
Esso Nant.	4844	584	174	545	NIL	80	134	240	1086	N/A	Use Cont Regen

1. N/A - Either not available or not identified in questionnaire
2. Not all of these streams go to process wastewater
3. All of the above sources of wastewater are continuous while the plant is operating with exception of some intermittent sources such as ballast water, storm run off, water treatment, and land farm leachate or run off. Scrubber liquids from Catalytic Reformer catalyst regenerator is a cyclic operation as noted.

4.7.5 Performances of Refineries Compared with Ontario Effluent Quality Objectives (OEQO)

Table IX shows how the refineries compare with OEQO during 1989 the year of monitoring. All numbers except as noted are annual average concentrations for December 1, 1988 to November 30, 1989.

TABLE IX
Annual Concentration Summary
for the Period Nov. 30 1988 to Dec. 1 1989

PARAMETER	Esso Sarnia	P.C. Miss.	P.C. Oak.	Nova Corunna	Shell Sarnia	Suncor Sarnia	Esso Nant.
COD mg/L	34.750	44.083	103.833	60.917	49.833	20.667	30.583
Chromium total ug/L	.000	125.950	88.548	244.317	17.952	.000	1.583
Copper ug/L	1.167	3.391	.667	6.083	4.167	15.000	2.917
Lead ug/L	3.333	23.091	2.000	.000	.000	.000	.433
Nickel ug/L	4.167	7.509	6.183	2.417	.833	1.667	1.167
Oil & Grease mg/L	.415	4.479	2.451	1.718	3.377	1.190	1.582
Phenolics (4AAP) ug/L	3.166	8.752	42.362	5.803	6.454	6.871	3.866
Total Suspended Solids mg/L	13.039	26.154	22.337	16.750	64.657	7.316	6.915
Zinc ug/L	17.335	91.226	402.032	437.211	32.969	51.667	27.000

Comparison with Table I shows that compliance on the average was generally good in 1989 with exception of total suspended solids which were a problem for 4 of the 7 plants. Petro Canada, Oakville also had a problem with zinc and phenolics.

All of the plants passed the fish toxicity test except Petro Canada Oakville which failed 3 of 12 samples due probably to high zinc concentrations in combination with chromium.

4.7.6 Performance of Ontario Refineries Compared with U.S. EPA BPT/BAT Limitations

Table X shows the U.S. EPA loadings which would have been applicable to the 7 refineries and the number of times the loading limitations would have been exceeded in 1989. Both daily maximum as well as 30 day average limits are shown. U.S. EPA limits impose a control on loadings (kg per day) not on flow.

Esso's Nanticoke Refinery met all U.S. EPA limitations on both a daily maximum and a 30 day monthly average. The 30 day average volume is used by EPA in the issuing of permits.

The remaining 6 refineries show varying degrees of compliance with the U.S. EPA 30 day monthly average as shown in Table XI. Compliance with BOD is not shown as it was not monitored in the 1989 program. The single largest area of non compliance was total suspended solids with 6 of the 7 plants not meeting prescribed limits.

TABLE XI
Level (%) of Compliance
With 30 Day
U.S. EPA Limitation

Parameter	Esso Sarnia	Shell Sarnia	Suncor Sarnia	Nova Corunna	PetroCan Oakville	PetroCan Mississauga	Esso Nanticoke
B.O.D.	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Total Suspended Solids	92	0	100	58	75	42	100
Oil & Grease	100	75	100	100	100	75	100
COD	100	92	100	100	100	100	100
Ammonia-N	100	100	100	100	100	75	100
Sulphides	92	100	100	25	58	58	100
Phenols	100	100	100	100	100	100	100
Chromium (total)	100	100	100	25	100	66	100

* N/D = no data available (BOD was not monitored)

Two of the 7 refineries have been in complete compliance while a third refinery would have been very close.

Table XII shows long term average performance concentrations established by EPA in 1974. These are levels which might be reasonably attained in a well run well designed treatment plant.

The monthly and daily variability factors were arrived at by statistical methods using data from exemplary refineries in the USA.

TABLE XII

PARAMETERS	DAILY AVERAGE VARIABILITY FACTORS	MONTHLY AVERAGE VARIABILITY FACTORS	LONG TERM AVERAGE CONCENTRATION mg/l
BOD5	3.5	1.7	15
COD	3.1	1.6	--
TOC	3.1	1.6	2.2 x BOD_5
TSS	3.3	1.7	10
Oil & Grease	3.0	1.6	5
Phenol	3.5	1.7	0.1
Ammonia	3.3	1.5	80% removal*
Sulphides	3.1	1.4	0.1
Cr 6	3.1	1.4	.005
Cr T	2.9	1.7	.25

* based on 80% removal in the sour water stripper

Daily maximum and monthly average concentration limits are calculated by multiplying the long term average concentrations by the daily variability factor and monthly variability factor, respectively.

4.7.7 Storm Water Handling and Treatment

Table XIII summarizes the methods used to collect and treat storm water. Generally the segregation of storm water follows the pattern established by "Petroleum Refinery Effluent Regulations and Guidelines" in 1974. These regulations classify storm water into two categories. Storm water which falls on areas where contamination might occur such as process areas, tank farms, pipe runs, roads, roofs and parking areas must be segregated and measured in order to qualify for a separate allowance for pollutants. On the other hand water falling on undeveloped areas where there is no likelihood of contamination occurring requires no treatment. Such areas must be diked and approval from the Ontario Ministry of the Environment is required to exempt these areas from collection and treatment requirements.

The MISA monitoring program in 1989 showed that storm water discharged to receiving water after ponding and testing did not contribute significantly to the loadings for some 16 parameters. The major problem seems to be total suspended solids which in some cases are colloidal clay particles difficult to settle out.

It is a common experience that infiltration of ground water through the hubs of sewer pipe in older plants can result in a significant flow into the storm water collection system during dry weather.

TABLE XIII
Storm Water Management

Plant	Developed Acres	Undeveloped Acres	Biological Treatment		Comments
			Treat all storm water	Possible to treat all storm water	
Esso Sarnia	145	300	YES*	---	Storm water is stored in tankage and treated in BIOX at a controlled rate.
Shell Sarnia	282	85	NO	YES**	Storm water is ponded, tested and either BIOX treated or released.
Suncor Sarnia	289	54	YES*	---	Storm water is ponded and then BIOX treated under controlled flow.
Nova Corunna	300	700	NO	YES**	Storm water is ponded, tested and either released or BIOX treated. If volume is too high 4 carbon beds in series provide treatment before release.
PetroCanada Oakville	260	37	NO	NO	Storm water is treated in BIOX to the extent possible. Storm water that does not go to BIOX goes to a surge lagoon where it is mixed with the final effluent.
PetroCanada Mississauga	345	66	YES*	---	Ponded and sent under controlled flow to BIOX.
Esso Nanticoke	450	1022	NO	YES	Storm water falling on process unit pads is BIOX treated. Other storm water is ponded, tested and released or it may be BIOX treated too.

STORM WATER - Runoff from developed areas of refinery (which may be partially treated).
* Includes runoff from process areas.
** Includes runoff from process areas which goes directly to process sewer.

4.7.8 Process Wastewater Flow Variability

Table XIV shows the minimum, maximum and monthly average volume of wastewater produced by each refinery during the monitoring period November 30, 1988 to December 1, 1989. This table shows that minimum and maximum flow ratio varies greatly from month to month due to seasonal temperature changes, variations in process rates, and the impact of storm water run off. The impact of storm water run off will vary according to a number of factors such as the degree to which the storm water is biologically treated, the amount of storm water absorbed by the soil, the size of the developed area and the rate at which the storm water can be processed in the treatment plant. Each plant has its own set of conditions which will influence the impact of storm water.

Table XIV
Monthly Average Flows
For All Seven Ontario Petroleum Refineries

Month	Esso Sarnia			Esso Nanticoke			Nova Corunna			Petro Canada Mississauga		
	min	max	avg	min	max	avg	min	max	avg	min	max	avg
88/12	22,766.600	29,697.600	26,272.181	2,944.000	7,828.000	5,248.222	2,976.000	7,685.000	4,918.742	6,581.000	13,930.000	9,166.419
89/01	22,076.800	31,197.500	26,270.077	3,795.600	8,229.600	6,202.523	4,265.000	7,942.000	5,630.290	4,179.000	13,467.000	8,959.258
89/02	21,269.400	28,829.100	25,295.029	2,845.200	13,353.600	7,042.786	2,124.000	6,995.000	5,362.571	4,601.000	12,059.000	8,591.214
89/03	18,461.900	27,593.700	22,061.265	678.000	11,160.000	6,025.581	1,779.000	10,638.000	6,428.733	5,496.000	14,262.000	9,601.646
89/04	22,067.000	26,892.000	24,281.900	4,913.000	14,812.000	7,941.667	2,876.000	9,107.000	6,865.633	7,780.000	15,720.000	10,965.867
89/05	24,742.000	49,866.000	32,248.677	5,465.000	14,414.000	7,718.516	3,663.000	6,458.000	5,205.806	4,592.000	12,783.000	8,583.935
89/06	27,134.000	35,943.000	31,369.789	3,600.000	9,546.000	6,733.621	1,057.000	11,225.000	6,219.467	5,996.000	22,029.000	13,388.400
89/07	26,966.000	34,082.000	30,761.452	1,638.000	8,490.000	6,347.321	2,986.000	9,744.000	6,673.774	5,859.000	25,708.000	11,558.667
89/08	26,524.000	33,787.000	29,694.968	4,268.000	8,550.000	6,016.700	1,706.000	7,768.000	6,073.065	7,001.000	32,231.000	12,935.484
89/09	26,354.000	38,528.000	33,078.567	4,661.000	8,216.000	6,403.700	645.000	10,808.000	5,376.310	7,091.000	18,047.000	12,019.167
89/10	24,954.000	32,791.000	28,555.871	4,180.000	8,268.000	6,344.548	2,816.000	8,080.000	5,446.258	7,319.000	18,048.000	11,665.258
89/11	21,098.000	34,093.000	27,295.733	751.000	8,658.000	6,556.833	.000	8,500.000	5,824.750	9,728.000	20,184.000	13,646.967
Avg	23,701.142	33,608.325	28,098.792	3,310.568	10,126.933	6,548.501	2,231.083	8,744.833	5,835.367	6,343.583	18,204.667	10,922.691

Month	Petro Canada Oakville			Shell Sarnia			Suncor Sarnia		
	min	max	avg	min	max	avg	min	max	avg
88/12	1,206.000	5,587.000	4,053.113	8,061.000	13,830.000	11,148.355	8,183.260	11,966.160	9,300.178
89/01	3,505.000	6,044.000	4,635.419	6,225.000	13,793.000	10,900.129	8,224.000	10,103.000	9,191.233
89/02	379.000	6,919.000	4,663.286	9,946.000	12,413.000	11,515.886	2,614.000	9,280.000	8,175.179
89/03	346.000	7,116.000	4,261.161	10,077.000	14,033.000	12,136.258	6,725.000	10,574.000	8,519.440
89/04	2,650.000	6,665.000	4,626.167	9,935.000	15,652.000	12,222.533	5,704.390	11,938.290	9,460.498
89/05	3,878.000	6,319.000	5,193.161	11,004.400	18,480.400	13,567.661	6,996.030	10,918.100	8,724.692
89/06	3,661.000	12,165.000	5,767.633	10,984.800	15,940.400	13,703.147	8,191.595	12,763.930	9,364.061
89/07	3,323.000	7,333.000	5,506.677	10,428.400	17,976.300	15,768.094	7,240.085	10,182.050	8,460.845
89/08	3,210.000	7,834.000	5,327.581	12,745.800	18,860.600	15,827.645	6,177.020	14,261.280	9,601.893
89/09	2,523.000	9,924.000	5,020.967	13,937.200	18,617.900	16,393.427	6,163.035	13,439.320	9,482.526
89/10	2,223.000	7,633.000	4,869.065	11,462.700	16,576.400	13,889.939	6,638.380	11,776.520	9,362.385
89/11	2,678.000	6,874.000	4,867.667	11,361.400	13,868.700	12,634.493	2,575.645	12,370.930	8,298.322
Avg	2,450.167	7,534.417	4,897.658	10,513.225	16,818.392	13,292.297	6,285.870	11,630.382	8,994.270

4.7.9 In Plant Reuse and Recycling Techniques

A number of techniques are commonly used by the Ontario refineries to reduce process wastewater production.

Cooling towers require the addition of chemicals to prevent scaling and corrosion in heat exchangers. The typical chemicals are organo phosphates (replacing zinc-chromates) sulphuric acid and chlorine plus fungicides and biocides to kill fungae and bacteria. The latter are used on a shock basis only. Increasing the number of cycles of concentration (the number of times the solids in the make up water are increased due to evaporation) reduces the blow down and therefore the loss of chemicals to the wastewater. Lime softening of the make up water can also help. The Ontario refineries operate between 4 and 8 cycles of concentration with the majority around 6.

Refinery pumps and compressors generally require water cooling for cooling of pump supports bearing jackets and stuffing boxes although the need for the latter has been reduced by mechanical seals. Some plants employ a closed recirculated water cooling system; much the same as the cooling system in an automobile. The removal of this source of wastewater can be significant where the large number of pumps and compressors are involved.

Stripped sour water is commonly used as wash water for the desalter. Not all refineries do this however. One plant maintains that it is beneficial to remove phenols from clean stripped water in the biological treater rather than from dirty desalter water. Desalter water is usually 5% of the crude charge volume.

Steam condensate from reboilers, steam traps and other sources is usually collected and returned to the steam plant. This condensate is hot and solids free making it valuable as water make up. The problem is the cost of providing a collection system to isolated small sources such as a field tank suction heater. Most plants follow a policy of condensate collection based on economic feasibility.

The reuse of storm water is not practiced in Ontario although it has a potential as make up to cooling towers after filtration for solids removal. The use of soft storm water would have several advantages. First, the water is soft requiring very little chemical treatment, thus it would reduce chemical costs. Secondly, it would increase the cycles of concentration thereby reducing the volume of blow down.

4.7.10 Treatment of Scrubber Water from the Regeneration of Catalytic Reformer Reactors

In order to maximize octane barrels and to ensure a high aromatic content in the reformate it is necessary to regenerate the platinum based catalyst used in the reactors. Most plants employ 3 or 4 reactors on line with a spare fresh reactor ready to be used. One refinery regenerated as many as 300 reactors in 1989. Regeneration practices vary.

Regeneration of the catalyst in a batch type reactor typically involves the following steps.

1. A preliminary burn at low O_2 to remove carbon.
2. An elevated burn at higher O_2 level to complete the process.
3. Sensitization of the regenerated catalyst with a chlorion.

During the first step air is injected into the recycle gas which is at a temperature of 700-750°F. O_2 level is kept low at less than 1%. This continues for 36-48 hours. The gases are then recirculated for another 2-4 hours after the O_2 level begins to increase. Next is the oxidation step. The temperature of the reactor bed is raised to about 950°F for 12 hours with the recirculated gases at 5-10% O_2. During both burns a chemical such as trichloroethane or chlorine is injected to activate the catalyst surface.

The recirculated gases contain CO_2, CO, O_2, N_2 and possibly dioxins (as it was discovered in Ontario in 1988). Some plants contact these gases with 15°Be Caustic solution in a closed scrubber. Sometimes the gases are water washed before release to atmosphere.

Under the present practices in Ontario refineries, the contaminated caustic phase plus the wash water may be sent to the wastewater treatment system directly or it may be filtered through a mixed media filter bed and then a granular carbon bed to remove any traces of dioxins.

There is no prescribed method for the treatment of the off-gases produced during the regeneration of batch type reactors as shown in Table XV.

TABLE XV
Methods Used By Ontario Refineries to Treat Gases from a Catalytic Reformer During the Regeneration Cycle

Plant	No. of Reactors Regenerated in 1989	Method of Treating Recirculated Gases	Method of Treating Discharged off Gases	Dioxin (2,3,7,8 TCDD) Concentration
Esso Sarnia	16	Reformer #1. Direct contact with wash water to treatment plant. Reformer #2. Air cooled condensate to treatment plant.	Alumina drier carbon	#1. regeneration water 0.203 ppt #2. 0.234 ppt in condensate
Shell Sarnia	300	Tower with 15°Be caustic on bottom and water wash on top. Water and caustic carbon treated before treatment plant.	None	Not detected in process effluent
Suncor Sarnia	3	Caustic scrubbing. Activated carbon filtration then to treatment plant.	None	Not detected in process effluent
Petro Oakville	6	Caustic scrubbing 15°Be then to treatment system.	None	Not detected in process effluent

- Nova Petrochemicals does not have a Catalytic Reformer
- Esso Nanticoke and Petro Canada Mississauga use continuous regeneration of catalyst without scrubbing of the flue gases which go to the atmosphere.

4.7.11 Treatment Sequences Used for Process Wastewater

All of the plants employ some type of primary treatment for oil/water separation, intermediate treatment for the further removal of oil and suspended solids followed by biological or secondary treatment for removal of dissolved organics. In addition 4 of the plants have holding or polishing ponds to further remove trace contaminants.

Six of the seven plants use recirculated active sludge for biological treatment and are of similar design and configuration. This type of biological treatment permits control of all the operating variables and unless an upset occurs the treated wastewater is not acutely toxic to Rainbow Trout.

The other plant Petro Canada Oakville uses 3 basins in series for aeration purposes. Each basin is aerated by underwater spargers. Sludge can be recirculated to the first basin. This system is not widely used in the Petroleum refining industry.

The following summarizes the treatment sequences at the 7 refineries.

Esso Sarnia	• API separators, Dual media filtration, Biological treatment,Clarification.
Shell Sarnia	• API separators, Dissolved air flotation, Equalization Biological treatment, Clarification.
Suncor Sarnia	• API separators, VTC (vertical tube coalescers), Equalization, IAF, Biological treatment, Holding pond.
Nova Corunna	• TPI (tilted plate interceptor), Holding pond, DAF, Biological treatment, Clarification, Granular Carbon (optional), Holding pond.
Petro Canada Oakville	• API separators, Mixed equalization, IAF, Biological treatment, Clarification, Aerated Polishing Pond, Mixed Media Filters, Holding pond.

Petro Canada Mississauga	• API separators, Mixed media filters, Equalization, Biological treatment, Clarification.]
Esso Nanticoke	• API separators, Equalization, D.A.F., Biological treatment, Clarification, Mixed media filters, Polishing Pond.

All of the plants employ some type of post API separator treatment such as D.A.F. (dissolved air flotation) I.A.F. (Wemco or induced air flotation) or mixed media filters (sand and anthracite). All of these treatment systems are roughly capable of producing the same removal of oil and suspended solids from the API separator effluent. Both DAF and IAF have the added advantage of air stripping gases either entrained or dissolved in the wastewater. In the case of Petro Canada Oakville these stripped gases are contacted in a caustic scrubber to reduce odour emissions.

It is worth noting that Suncor, Nova Petrochemicals, Petro Canada Oakville and Esso Nanticoke have holding ponds before discharge of the wastewater to the receiving water. These ponds are effective in further removing trace levels of contaminants and may be considered part of a tertiary treatment system.

5.0 CURRENT STATUS OF ESSO PETROLEUM'S SARNIA REFINERY

5.1 Plant Description

Esso Imperial Oil has been a part of the Sarnia/Lambton community for almost 100 years, but most of the present plant dates from 1951. It is located in Sarnia Ontario and employs about 2,000 people.

The saleable products are:

- gasolines;
- jet fuel;
- diesel fuel;
- furnace oil;
- benzene;
- toluene;
- xylene;
- kerosene;
- stove oil;
- aliphatic solvents;
- aromatic solvents;
- propane;
- lubricating oils;
- wax;
- sulphur;
- pitch; and
- chemical additives.

5.1.1 Refinery Process Data

Note: All data is in M^3/day.

Process	1989 Stream Day Capacity	1989 Calender Day Capacity	Installed
Crude Unit	21144	17976	1951
Crude Desalting	21144	17976	1951,1968
Vacuum Tower	4796	4538	
Fluid Coking	9538	3366	1967
Fluid Cat. Cracking	4769	4219	1951
Hydro Cracking	1828	1649	1976
Catalytic Reformers (Powerformer)	5564	3481	1956,1969
H.F. Alkylation	1192	914	1972
Lube Oil Processing (includes)		3665	1956,1971,1989
Phenol Extraction		1713	
Ketone Dewaxing		912	
Lube Hydrofining		954	
Lube Vacuum Tower		86	
Hydrogen Plant (Production)	707900	602100	1976
Sulphur Recovery Plant Production LTD	140	101	1960,1970,1989
Hydrogen Treating	16375	10208	1960-1984

5.2 Feedstocks Run in 1989

In 1989 there were six different crude feedstocks run. These accounted for 98% of all the feedstocks used for that year. The crude feedstocks were as follows:

Name	% Run	% Sulphur	API Gravity
Light Sour Blend	36	1.3-1.5	34-35
Sweet Mix Blend	24	0.5	38
Lube Blend	5	0.35-0.45	38-39
Cold Lake Blend	20	3.0-3.3	24-26
Smiley Coleville	5	2.5	24-25
Sarnia Special Stream	10	0.5-0.7	31-37

All of the crude comes from Western Canada. The Sarnia Special Stream comes from the Strathcona refinery in Edmonton and is a mixture of pitch and light atmospheric gas oil.

5.3 Chemicals Used

See appendix, Section 5.15.

5.4 Water Management

5.4.1 Water Supply

The St. Clair river provides water for the plant. Water is used primarily for cooling, processing, and steam generation. There are four water pump houses which supply the water to the refinery and chemical plant. Water pumped varies between 273,000 and 363,000 M^3/day, depending on the season. No chlorine was required in 1989 but in 1990 Zebra Mussel control will require 0.5 - 2 ppm dosage of chlorine. Dechlorination using sodium metabisulphite will be carried out at the outfall of the once through cooling water.

5.4.2 In Plant Reuse and Recycling Techniques

Wash water used in the saturated light ends unit (SLE) is recycled, and any spent wash water is eventually sent to the biological treater.

Water used in the cooling tower is recycled at a rate of 76,314 M^3/day approximately 1.5 cycles of concentration are maintained. At this low cycle of concentration, no addition of water treatment chemicals is normally required. On occasion chemicals must be added for bacteria control. The towers operate at a differential temperature of 7C° or 12F°.

The sour condensate from the crude towers (AVIS and CCIS) may be recycled to the desalter, but is normally stripped to remove ammonia and hydrogen sulphides, held in a storage tank and then directed to a biological treater. Experience shows that it is more efficient to remove the phenols from a stripped stream than from the desalter effluent.

Studies are currently underway to increase steam condensate collection and generally to reduce water use in every way possible.

5.4.3 Ratio of Wastewater to Feed Charge

Based on charge rate to the Crude Unit the refinery produced 1563 M^3 of process wastewater for each 1000 M^3 of feedstock. The Chemical Plant wastewater contributes 22% of this flow. Deducting the Chemical Plant contribution the ratio for the refinery alone becomes 1219 M^3 per 1000 M^3 of feedstock.

The refinery/Chemical Plant complex produces 55 Canadian gallons of process wastewater for each barrel of feedstock to the refinery. The refinery alone produces 43 Canadian gallons per barrel of feedstock.

In terms of Federal Regulations and Guidelines the ratio is 38 Canadian gallons per minute per 1000 BPD charge for the complex and 30 for the refinery alone.

5.4.4 Cooling Methods Used

Most of the cooling is done by once through cooling water which provides 75% of the heat removal. Recirculated cooling water makes up 20% while air cooling represents about 5%. Studies are underway to reduce the amount of cooling water used. An application has been made for a Certificate of Approval to chlorinate the inlet and dechlorinate outfall of the once through cooling water to control Zebra Mussels.

5.5 Segregation of Sewer Systems

1. *Sour Water*

Sour water is collected throughout the plant at the rate of 350-400 barrels per hour and stored in special tanks to prevent odour emissions. It is steam stripped to remove ammonia and hydrogen sulphide.

2. *Process Wastewater*

This consists of boiler blowdown, cooling tower blowdown, ballast water and contaminated storm water run off and water which has been in direct contact with hydrocarbons.

3. Storm Water

All storm water falling on process areas is routed to the process water sewer and collected in storage tanks which provide equalization capacity and sufficient retention for a once in 10 year storm or alternatively 2 inches of rain in a 2 hour period. This water is then injected on a controlled basis into the biotreater.

4. Once Through Cooling Water

No. 1 Plant, No. 2 Plant north and No. 2 Plant south each have their own separate systems of collection. Water is routed through API separators prior to discharge to the river.

5. Sanitary Wastewater

Sanitary waste is collected and goes to the Sarnia municipal sewer system for treatment.

5.6 Sources of Wastewater

The total volume of process wastewater as measured by the MISA program in 1989 averaged 28189 M^3/day. Approximately 22% of this water originated in the Chemical Plant.

A number of specific sources of process wastewater have been singled out because they may offer an opportunity for flow reduction.

	M^3/day	Source
Ballast water	174	Ships
Storm water	1900	Refinery & Chemical Plant
Blowdown from water treatment	N/A	Refinery
Boiler blow down	324	Refinery
Cooling tower blow down	1090	Chemical Plant & Refinery
Pump glands	220	Refinery
Compressor glands	150	Refinery
Desalters	1145	Refinery
Landfarm leachate and tank water draw off	N/A	Refinery
Stripped sour water	1750	Refinery

5.7 Opportunities to Reduce Wastewater Flow

The bulk of process wastewater comes form numerous sources within the process units and only an in depth study of water use could identify candidates for reduction. This study is underway and should be complete in the near future.

The pump and compressor glands contributed a very small percentage of the wastewater but might be reduced by means of a closed cooling system. Again the stripped sour water 1750 M^3/day or 6% of the total wastewater is now biologically treated adding to the total volume of wastewater. A re-use for this solids free water should be considered.

5.8 Description of Wastewater Treatment System

5.8.1 Discussion of Schematic

Once through cooling water is treated in four parallel API separators for solids and oil removal prior to discharge. These separators are illustrated as #3, #9, #11, and #12 on the schematic. Separators #3 and #9 have their own individual outfalls to the St. Clair river. Separators #11 and #12 have a common outfall which also combines with the biological oxidation plant outfall. This common outfall extends 150 feet out into the St. Clair river while the outfall for separators #3 and #9 discharges at the river bank. Separator #9 is equipped with sheen and TOD analyzers. Separator #3 has a TOD analyzer.

Process wastewater is treated in three parallel API separators for solids and oil removal. These separators are illustrated as #5, #10, and #14 on the schematic. The water from each of these separators is treated by dual media filters. The sand and anthracite filtration media remove oil and suspended solids. The water goes to a biological treatment, clarified and then discharged into the clean OTCW from Plant 2. The combined flows have a common outfall.

Storm tankage is available at each separator in order to contain runoff. The tanks are designed to hold a one in ten year storm event, thus preventing an overload of the treatment facilities. The water is then fed through the wastewater treatment system.

Sour waters are collected through the plant from a number of sources, then steam stripped to remove sulphides and most of the ammonia in a single stage stripper. The stripped ammonia and hydrogen sulphide go to the sulphur recovery unit. Storage is provided in case the stripper is shut down. The stripped water then goes to 2 parallel older packaged biological treatment units (Aero Accelerators) with combined aeration and clarification functions. Phenols present in the sour water are largely removed. The treated water is normally routed to the main biological treatment units, but may also be routed to the API separators or the dual-media filters as required.

Sanitary waste is segregated and goes to the municipal treatment system.

During 1989 the plant regenerated some 19 batch reactors from the two Catalytic Reforming Units. The gases produced during the regeneration of these reactors are water scrubbed. The water phase has been shown to contain an extremely low concentration of dioxins. As a precaution the water phase is passed through dual media filters and then to the biological treatment system. No dioxins have been detected in the final effluent from the plant. Levels in the scrubber water average 0.23 parts per trillion of 2,3,7,8 TCDD toxic equivalents.

5.8.2 Sampling and Monitoring Frequency for Outfalls

Location	Parameter	Frequency
#3, #9, #11, #12 Composite sample	Oil & Grease	4/week
	TOC	2/week
	Flow	Continuous
#9 Outfall	pH	7/week
	Phenolics	7/week
	Flow	Continuous
	Sheen detector	Continuous
#11, #12 Outfall	pH	7/week
	Phenolics	7/week
	Flow	Continuous
#3 Outfall	pH	7/week
	Phenolics	7/week
	Flow	Continuous
	TOD	Continuous
Biox Effluent	Oil & Grease	4/week*
	Suspended Solids	4/week*
	Ammonia	4/week*
	TOC	2/week*
	Fish Toxicity	1/month
	Flow	Continuous
	TOD	Continuous

5.8.3 Summary of MISA Process Effluent Results for 1989

The following data are results from the 12 month Misa monitoring program.

Priority Pollutants Found in Process Effluent
Esso Petroleum Canada (Sarnia)
MISA Monitoring Data Dec 88 to Nov 89

Parameter	Min	Max	Avg	Unit	Loading Kg/day	Avg Concen. 1989 mg/L	Ontario Objective mg/L
1,2-Dichloroethane	.00	.40	.08	ug/L	.00		
Aluminum	.00	384.00	85.42	ug/L	2.40		
Ammonia plus Ammonium	.00	11.00	.56	mg/L	15.74	0.56	10
Antimony	.00	9.00	.75	ug/L	.02		
Arsenic	2.00	13.00	8.33	ug/L	.23		
Benzene	.00	21.90	1.61	ug/L	.05		
COD	28.00	41.00	34.75	mg/L	976.43	34.75	200
Cadmium	.00	3.00	.42	ug/L	.01		
Chloroform	.00	.50	.07	ug/L	.00		
Copper	.00	14.00	1.17	ug/L	.03	.001	1
Cyanide Total	.00	.09	.02	mg/L	.56		
DOC	.00	17.00	9.60	mg/L	269.75		
Ethylbenzene	.00	24.30	1.20	ug/L	.03		
Hydrogen ion (pH)	7.00	8.40	7.63				
Lead	.00	40.00	3.33	ug/L	.09	.003	1
Methylene Chloride	.00	1.90	.45	ug/L	.01		
Nickel	.00	30.00	4.17	ug/L	.12	.004	1
Nitrate + Nitrite	3.69	8.35	6.01	mg/L	168.87		
Oil and Grease	.00	9.70	.41	mg/L	11.52	.41	10
Phenol	.00	3.30	.27	ug/L	.01		
Phenolics (4AAP)	.00	19.00	3.17	ug/L	.09	.003	.02
Selenium	.00	24.00	15.67	ug/L	.44		
Sulphide	.00	.60	0.04	mg/L	1.12		
TOC	2.30	88.00	14.03	mg/L	394.23		
Toluene	.00	17.10	2.44	ug/L	.07		
Total Kjeldahl Nitrogen	.81	1.26	.99	mg/L	27.82		
Total Phosphorus	.00	34.80	1.27	mg/L	35.69		
Total Suspended Solids	1.90	46.20	13.04	mg/L	366.41	13.04	15
VSS	.00	56.70	11.23	mg/L	315.55		
Vanadium	.00	70.00	9.17	ug/L	.26		
Zinc	.00	42.00	17.33	ug/L	.02		
m-Xylene + p-Xylene	.00	55.30	2.95	ug/L	.08		
o-Xylene	.00	29.70	2.12	ug/L	.06		

Avg daily process flow 28,098.792 m^3/day

5.9 Comparison of Process Effluent Quality with Ontario Effluent Quality Objectives

During the 1989 MISA monitoring program all of the parameters included in the Ontario Objectives for Refineries (See Section 4.2) were monitored. Chromium was not detected. The concentration limits in these objectives were all met with the exception of total suspended solids. The monthly tests on the wastewater showed no acute lethality to Rainbow Trout.

5.9.1 Comparison with U.S. EPA BPT/BAT Limitations

During 1989 the following number of exceedences would have occurred if the U.S. EPA BPT/BAT limitations had been applicable.

Daily maximum limits	• Total Suspended Solids	5
	• Sulphides	2
30 day average limits	• Total Suspended Solids	1
	• Sulphides	1

5.10 Fundamental Factors Affecting Effluent Quality

As noted in Section 5.9 the average values for the controlled contaminants under the Ontario Effluent Quality Objectives for Petroleum Refineries were well below the limits. Variability in day to day operations is probably responsible for the high values.

This is a fairly old plant with many of the process units 20 to 40 years old. Segregation of once through cooling water and process water is virtually complete.

The chemical plant produces a wide variety of solvents, alcohols, etc. and is integrated with the refinery insofar as wastewater treatment is concerned. Contaminants not common to refineries are therefore introduced into the system. Conventional biotreatment is designed for the removal of soluble organics.

In 1989 the plant ran 6 different crude feed stocks. One of these crudes contained 3% sulphur with 25°API gravity. Such a combination complicates the desalting process and produces high concentration of hydrogen sulphide and ammonia in the sour condensates.

The refinery depends on once through cooling water for 75% of its heat removal. Heat exchangers are therefore sized for a 40F° increase in water temperature versus about 20F° for a cooling tower system. Replacement of these exchangers to accommodate a recirculating cooling water system would therefore be required. Air cooling is used on a small scale but has been found to create some noise problems.

A common problem in the Sarnia area is colloidal clay particles present in the storm water run off. These fine particles resist settling in the waste water system and can produce elevated suspended solids in the effluent.

The ratio of process water to feedstock falls between the limits for new and existing refiners as set by Federal Regulations and Guidelines for Petroleum Refineries. Since the recirculated cooling water system operates on only 1.5 cycles of concentration there has been no need to add chemicals such as organic phosphates to control corrosion and scaling.

5.11 Control Orders Issued

None outstanding.

5.12 Capital and Operating Costs for Wastewater Treatment System

The refinery spent about $90 million (in 1989 dollars) between 1976 and 1989 to bring the wastewater treatment system to its present level. Annual operating costs for labour, maintenance, utilities, chemicals, etc. amount to $2.7 million dollars per year.

5.13 Best Management Practices

5.13.1 Training

The operators working in the wastewater treatment area have an operating manual developed by Esso. The manual is divided into self learning and testing modules. A training coordinator is responsible for following up on each operator's progress. Each year operators receive a 3 day course to discuss new equipment. It is planned to send all new operators for a 5 day course at Lambton College.

5.13.2 Manuals

There is a three volume manual for the wastewater treatment plant which is called the WETS manual. This manual provides guidance in the areas of troubleshooting, start up and shut down procedures, and emergencies.

There is also a waste disposal guide which identifies proper waste management procedures within the plant.

5.13.3 Specifications

Wastewater treatment operators each have a mini manual which is a condensed version of the operating manual. The manual is quite compact and outlines operating parameters for critical pieces of equipment. This allows the operator quick access to information on hand.

5.13.4 Responsibility/Authority

The shift superintendent is in charge of the plant after regular working hours. He reports any spills to the MOE and initiates response action.

Many people have a full and part-time responsibility for water treatment. They include:

- approximately 10 people part-time from leadership teams because a person from each team is responsible for the water quality leaving their area;
- one person dedicated solely to the maintenance of the water treatment (WETS) plant;
- 4 full time shift operators; and the
- environmental manager.

5.13.5 New Projects

All large projects must be accepted by the environmental department prior to being approved by the capital budgeting committee.

Projects having an effect on safety, health, or the environment receive priority. Priorities of smaller scale projects are determined on a daily basis by the maintenance person assigned to the WETS system.

20-25% of the capital budget is targeted for environmentally related projects in the water treatment system. Approximately $4-5 million per year is spent on environmental projects. A long term plan exists for future wastewater treatment plant projects.

Presently an extensive flow balance throughout the entire process system is being performed with a view to reducing wastewater.

5.13.6 Oil Spills in Plant

Only one spill of undetermined size of benzene, toluene and xylene into the #5 separator occurred in 1989. This spill did not affect river water quality.

A source control program is presently underway which will aid the identification of the spill source. A guide exists which helps the shift superintendent identify a spill.

The spill response team on site is equipped with boats, booms, skimmers, chemicals, and three vacuum trucks to clean up any spills. The spill commander is responsible for coordinating all functions within the team.

Outside contractors are available if the spill response team cannot cope with the spill. The Blue Water Clean spill team is available to help clean up the spills.

5.13.7 Landfarming

A fenced off landfarm is in operation as a waste management system. Employees are instructed as to the types of materials which can be landspread. The laboratory analyzes all materials prior to being put on the landfarm and the soil is analyzed monthly during the landfarm season.

5.14 Conclusions

This is a highly complex plant which has been updated on a large scale. Over the years there have been a number of additions to the wastewater collection and treatment system. These have resulted in a good state of the art primary and secondary treatment normally meeting the concentration levels set by the Ontario Effluent Quality Objectives. Occasionally some of the concentrations did not meet the objectives.

The amount of process wastewater is fairly high, however some further water reductions are being sought. One of the problems is thought to be cross connections between the once through cooling water system and the process wastewater.

The wastewater treatment operators undergo a comprehensive training program with a 3 day update per year. It is planned to send all new operators to a course at Lambton College. An excellent training manual has been developed by CPPI for operator training and this will be used as a basic text.

No detectable levels of dioxins or furans have been detected in the effluent.

Top priority is given to health, safety and environment work orders. An environmental representative on each of 10 leadership teams ensures prompt action and good communications.

The plant is equipped to handle small spills and is a member of the co-operative known as Blue Water Clean.

5.15 APPENDIX

- chemical used
- process flow schematic
- waste water schematic

CHEMICALS USED

Atmospheric and Vacuum Unit (AVIS)	-	ANHYDROUS AMMONIA CAUSTIC ($NaOH$) ALCHEM 5E91 (fatty acid esters in heavy aromatic naptha solvent < 70%) ALCHEM 169 (amide-imidazoline in an alkyl aromatic naptha [<65%] and z-propanol [<3%]) METHYL ALCOHOL
Alkylation Unit (ALIS)	-	HYDROFLUORIC ACID POTASSIUM HYDROXIDE LIME SODA ASH CAUSTIC ($NaOH$) ACTIVATED ALUMINA MEROX (WS) (catalyst)
Fluid Catalytic Cricking Unit (FCIS)	-	COMBUSTION PROMOTER (Davidson Chemicals) ALCHEM 5163 (mixture of fatty acids and fatty acid amides)
Fluid Cooker (CCIS)	-	ALCHEM 169 AMMONIA CAUSTIC ($NaOH$) ALCHEM 5E41 (fatty acid esters in heavy aromatic naptha solvent <70%)
CO Boiler (COB)	-	DEARBORN 698 (mixture of polymer and removal agents to keep boiler heat surfaces clean) DISODIUM PHOSPHATE DEARBORN 3904
Sulphur Plants (SRIS)	-	CAT LIGHT HEATING OIL
Hydrocracker Unit (HCIS)	-	SULPHIDING AGENTS (commercial grade ethyl mercaptan or dimethyl sulphide free of nitrogen or metal contaminants) NEUTRALIZING SOLUTION (5 wt% sodium or potassium carbonate, 0.5 wt% sodium nitrate, trisodium wetting agent, and condensate 50 ppm chlorides)
Hydrogen Synthesis Unit (HSIS)	-	CATACARB (potassium carbonate, patented catalyst, corrosion inhibitor, 45% potassium hydroxide, 35% hydrogen peroxide, anti-foam agent) DEARBORN 698 SLUDGE CONDITIONER DEARBORN 817 PHOSPHATE DEARBORN ALKAMEEN C INHIBITED ETHYLENE GLYCOL
Hydrogen Purification (HPIS)	-	DESICCANT FREON - 12

Central Treating Plant (CTP)	-	MEROX (WS) CAUSTIC (mixture of Merox catalyst and 12° Be (NaOH) caustic 20° and 12° Be (NaOH) 50° Be (NaOH) Caustic
Power Former Units (PFIS)	-	TRICHLOROETHYLENE HYDROGEN CHLORIDE HYDROGEN SULPHIDE ALUMINA DESICCANT
Saturated Light Ends Unit (SLE)	-	MONOETHANOLAMINE (15-20 wt%) MOBIL SORBEAD ANTI-FOAM AGENT (Dow Corning)
Light Ends Recovery (GCIS)	-	CAUSTIC MONOETHANOLAMINE AMERSTAT 320 DREWSPERSE 738 DREWGAURD 187B SODIUM HYPOCHLORITE PEETROMEEN AF 116 ALCHEM 537 NUTRAMEEN NA-5 SODIUM SULPHITE TRI SODIUM PHOSPHATE CAT LIGHT HEATING OIL
Utility Plant (UTIS)	-	HYDRATED LIME LIME TREET (CaO) SODIUM SULPHITE - CATALYSED DEARBORN 698 DISODIUM PHOSPHATE ANTHRACITE ZEOLITE (ion exchange resin) ZEOQUEST (ion exchange resin)
Hydrotreaters (MHIS)	-	NEUTRALIZING SOLUTION (58 wt% sodium carbonate, 9.5 wt% sodium nitrate, and 2 gal/1000 gal of corexit 7664 (wetting agent))
BIOX	-	PHOSPHORIC ACID CAUSTIC SULPHURIC ACID AMMONIUM HYDROXIDE LIME KEDCHEM ISLS 9955 (flocculant) ANTHRACITE SAND

Lubricating Oil Complex -

PHENOL
PROPYLENE
METHYL ETHYL KETONE
METHYL ISOBUTYL KETONE
COBALT MOLYBDATE
ACTIVATED ALUMINA DESSICANT
METHYL ALCOHOL

The following types of additives may be used in the blending of oils
"VI" IMPROVER
EXTREME PRESSURE ADDITIVES
(such as sulphurized fats, chlorinated hydrocarbons, or amine phosphates)
POUR DEPRESSANTS (such as polymethacrylates)
ANTI-FOAMS (such as silicone oils or polyesters)
EMULSIFIERS (such as salts of sulphonic acids)
TACKIFIERS (such as polyisobutylenes)
FRICTION MODIFIERS (such as fatty acids, fatty amines, and fats)
ANTI-WEAR ADDITIVES (such as zinc dialkyl-dithiophosphates or tricresil phosphates)
RUST INHIBITORS (such as alkyl succinic acids or salts of sulphonic acids)
DISPERSANTS (polymers such as nitrogen containing polymethacrylates, alky succinimides, succinate esters, or high molecular weight amines and amides)
DETERGENTS (such as normal or basic calcium barium, or magnesium compounded with phosphates, phenates, or sulphonates)
METAL DEACTIVATORS (such as dimercaptothiadiazole or any such derivates or diamines of triarylphosphites sulphur compounds)
ANTI-OXIDANTS (such as hindered phenols, amines, or zinc dithiophosphates)
CORROSION INHIBITORS (such as zinc dithiophosphates or sulphurized olefins)

Higher Olefins Process (HOIS) -

PROPANE
ETHANE } (feed)
PROPYLENE
DI-TERT- P CRESOL (antioxidant) PHOSPHORIC ACID ON KIESELGUHRCLAY (catalyst)
PALLADIUM ON ALUMINA (catalyst)

Paramins Plant -

MALEIC ANHYDRIDE
POLYAMINE
BORIC ACID
NONYLPHENOL
SULPHUR DICHLORIDE
PLEXOL 305

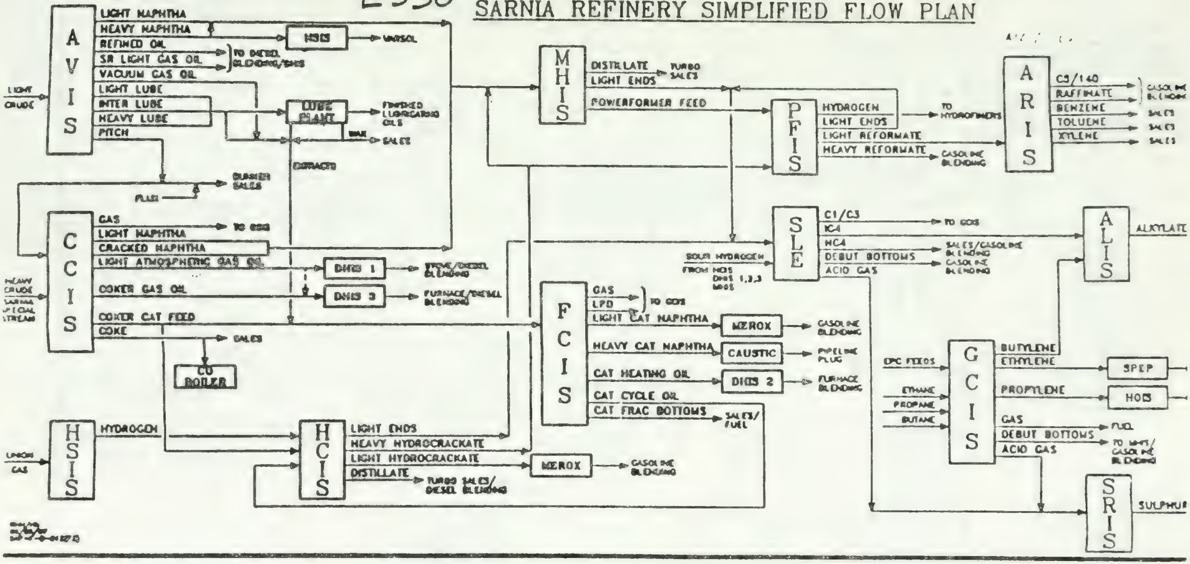
Feed - PARANOX 15 (zinc/phosphorous)
SULPHONIC ACID
CERCLOR 51 L
DIETHYL TRIAMINE
OLEIC ACID
BREAXIT 8491
DMA-4
SULPERM 110
DIATOMACEOUS EARTH
CHLORINE
DI-T-BUTYL PEROXIDE
CAUSTIC (NaOH)
SULPHURIC ACID
DOW CORNING 200 FLUID
ATF ANTIFOAM
ANTIOXIDANT 300

Naptha Specialties Plant (NSIS) - feed - LIGHT VIRGIN NAPTHA
HEAVY VIRGIN NAPTHA
AROMATICS UNIT RAFFINATE
SOLVESSO BASE
ISOPAR BASE
CHAR
METHANOL
ANTIOXIDANT F-30

Once through Cooling Water (OTCW) - CHLORINE
ALCHEM 321
SODIUM HYPOCHLORITE
DREWGUARD 187b (corrosion inhibitor)
DREWSPERSE 738 (dispersant)
AMERSTAT 320 (biocide)
SOUR WATERS

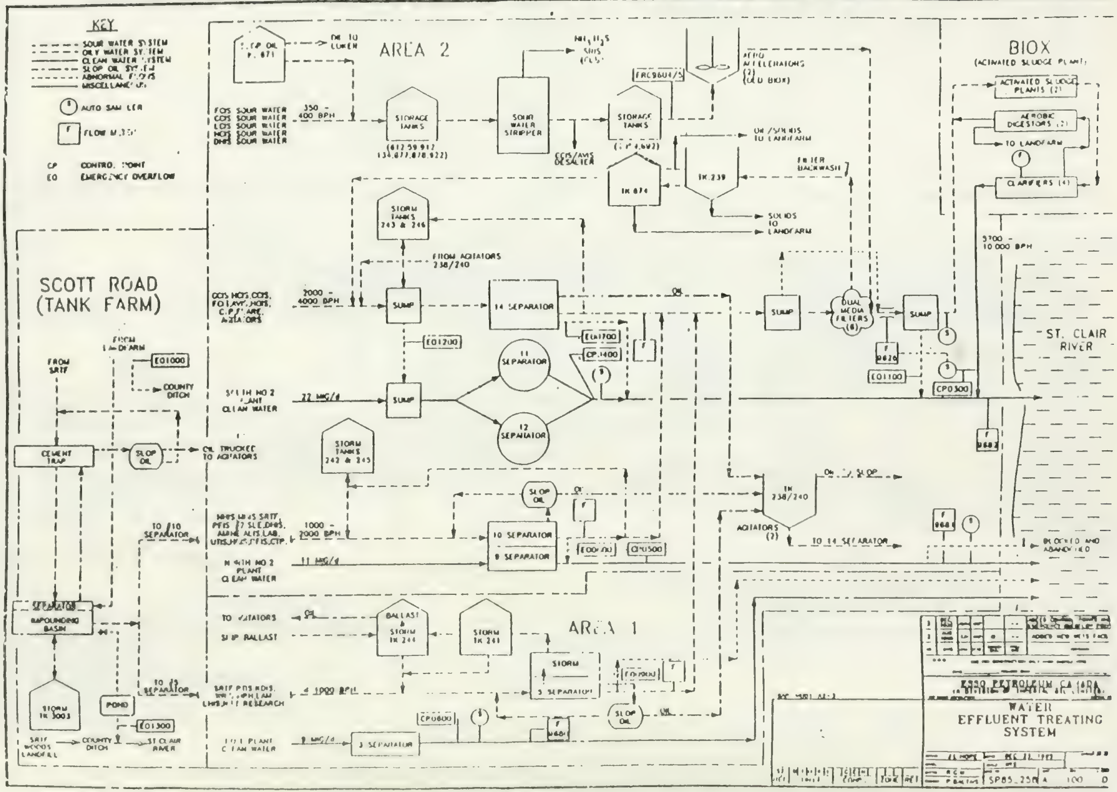
Hydrogen Synthesis Unit (HSIS) - SUMP WATER
GLYCOL
CATACARB SOLUTION

ESSO SARNIA REFINERY SIMPLIFIED FLOW PLAN



ESSO-SARNIA

ESSO PETROLEUM - SARNIA REFINERY



6.0 CURRENT STATUS OF NOVA PETROCHEMICALS CORUNNA REFINERY

6.1 Plant Description

Nova Petrochemicals is located at Corunna near Sarnia and went on stream in 1978. It was built primarily to provide feedstocks to chemical plants located in the area. Some products are marketed directly while others consisting of mixtures and hydrocarbon components are sent to the conventional refineries for further processing or blending into products. The following materials are sold either directly or indirectly to other companies:

- benzene;
- toluene mixture;
- xylene mixture;
- motor gasoline components;
- diesel fuel;
- furnace oil;
- heavy fuel oil;
- synthetic natural gas; and
- feedstocks for the chemical plants.

6.1.1 Refinery Process Data

Note: All data is in M^3/day.

Process	1989 Stream Day Capacity	1989 Calendar Day Capacity	Year Installed
Crude Unit	8576	7350	1978
Crude Desalting	8576	7350	1978
Vacuum Tower	--	1600	1982
Thermal Cracking	8597	7372	1978
BTX Extraction and Hydrogen Treating	2063	1668	1978

6.2 Feedstocks Processed in 1989

In 1989 a wide variety of various feedstocks were processed as listed below.

Name of Feedstock	% Total Run	% S	API°
Mixed Sweet, Alberta	46.7	0.42	38.5
Purchased feeds-ethane, propane, C4's, naphtha, light oils	35.5	0 - 0.2	0
Dome/Sarnia Condensate	10.5	0.11	73.5
Western Condensate	3.2	0.19	54.0
Chilap Naphtha	2.6	0.35	54.0
Brent, Syncrude, Coop, West Texas, Intermediate, Benny Light, Coop	1.5	0.14 - 0.49	32.0 - 42.2
Total	100.0		

Compared to other refineries in the Sarnia area, Nova Petrochemicals runs very low sulphur feedstocks with a high API gravity.

In 1989 the plant processed 11405 M^3/C.D. of feedstock of which 4055 M^3/C.D. was purchased petroleum fractions for charge to the Thermal Cracking Unit.

6.3 Chemicals Used

See appendix Section 6.15.

6.4 Water Management

6.4.1 Water Supply

A water pump house on the St. Clair River supplies 17000 M^3/day. The municipality supplies drinking water.

6.4.2 In Plant Reuse and Recycling Techniques

Surface run off is ponded and supplies fire water during an emergency.

Pump and compressors glands are almost 100% cooled by a closed cycle system.

Water used in the cooling tower is recirculated at a rate of 810,000 M^3/day at 7 cycles of concentration. Water treatment chemicals, such as phosphate based additives and tolyetriazole are added. The tower operates at a temperature differential of 13C° or 23F°.

Wastewater flow reductions are being planned for the future. Urinal headtanks are being changed to a single flush operation. This will reduce the flow to the sanitary system and the consumption of potable water and reduce the process wastewater flow.

Steam condensate is collected and returned where possible.

6.4.3 Ratio of Wastewater to Feed Charge

Based on charge rate to the Crude Unit and the purchased feedstocks charged to the Thermal Cracker unit, the plant produced 511 M^3 of process wastewater for each 1000 M^3 of crude processed.

The plant produced 17.9 Canadian gallons of process wastewater for each barrel of feedstock processed. In terms of Federal Regulations and Guidelines for Petroleum Refineries the rate is 12.4 Canadian gallons per minute per 1000 B.P.D. charge rate. The standard for new refineries is 20 so this plant is below the Federal Regulations.

6.4.4 Cooling Methods Used

The refinery is 100% cooled by cooling towers. Once through cooling water is not utilized at the refinery and air cooling use is negligible. Cooling water is recirculated at the rate of 810,000 M^3/day.

6.5 Segregation of Sewer Systems

Five sewer systems exist on the site. They are as follows:

1. *Chemical Sewer*

   This sewer system contains effluent from the crude unit desalter, olefins caustic neutralization system, aromatics extraction unit, laboratory, and various holding tanks.

2. *Oily Water Sewer*

   This system contains treated wastewater from the sanitary sewage plant, process area drainage, rail and truck loading area drainage, cooling tower blowdown and contaminated tank dyke drainage.

3. *Storm Water Sewer*

Uncontaminated storm water is collected separately from roofs, roads and French drains parallel to the roadways. A second system collects potentially contaminated stormwater from the dyked tank farm areas. The remaining areas such as the process pads, shipping areas and cooling tower blowdown go to the oily water system.

4. *Sanitary Sewer System*

Sanitary sewage is collected separately and treated biologically.

5. *Landfarm Leachate System*

Leachate is collected and is treated biologically or it may go to Baby Creek.

6.6 Sources of Wastewater

The total volume of process wastewater as measured by the MISA program in 1989 averaged 5831 M^3/day.

The process units produce the bulk of this water however a number of sources have been identified and quantified because they may provide opportunities for further water use reductions.

	Annual Average Flow M^3/day
Cooling tower blowdown	1800
Boiler blowdown	N/A
Desalter	845
Stormwater	N/A
Stripped sour water	869
Landfarm leachate	N/A

6.7 Opportunities for Reduction in Wastewater Flow

There is no obvious place where selected wastewater streams could be further reduced in volume. The ratio of process wastewater to feedstock is already well below generally accepted levels.

6.8 Description of Wastewater Treatment System

6.8.1 Discussion of Schematic

Water from the chemical sewer undergoes primary oil separation in a corrugated plate interceptor. The effluent water is held in an equalization basin, then sent to a flash mix tank where alum is added. The wastewater and alum mixture is sent to a floc formation tank, then to a dissolved air floatation (DAF) unit to further remove suspended solids. The wastewater stream from DAF is sent to one of two biological treatment units where phosphoric acid may be added. The biologically treated water is sent to a clarifier and then it may be further treated through four activated carbon filters, but normally this is not needed and the filters are bypassed. From the final effluent ponds the treated water may be recycled through the treatment plant or directly discharged to the St. Clair river. The clarified sludge is digested aerobically and then landfarmed.

An oily water sewer collects sanitary sewage from the shipping area, drainage from the process area, drainage from rail and truck loading as well as cooling tower blowdown and contaminated water inside tank compounds. This waste stream parallels that of the chemical sewer and receives the same full treatment.

Storm water from undeveloped areas is routed to a holding pond, tested and if it is within OEQO it goes to the river. If the quality is not satisfactory it is routed through the wastewater treatment system. The pond also serves as a reservoir for firewater in case of an emergency.

Leachate from the landfarm can go either directly to Baby Creek or it may be routed back through the complete treatment system if required.

Sanitary sewage is treated by means of two rotating biological treatment units designed for this purpose. The effluent goes directly to the final effluent pond along with cooling tower blowdown and neutralized water from the demineralization system.

6.8.2 Sampling and Monitoring Frequency

A single outfall is sampled once per day for the following parameters:

- oil and grease;
- suspended solids;
- ammonia N;
- TOC (total organic carbon);
- phenolics;
- flow.
- pH;

Daily grab samples are taken to monitor pH and phenolics. Sulphides are monitored 3 times per week, and fish toxicity is done once a month.

6.8.3 Summary of MISA Process Effluent Results for 1989

Pollutants found in the effluent streams during the MISA monitoring analysis are shown below.

Priority Pollutants Found in Process Effluent
Nova Petrochemicals Inc. (Corunna)
MISA Monitoring Data Dec 88 to Nov 89

Parameter	Min	Max	Avg	Unit	Loading Kg/day	Avg. Concen. 1989 mg/L	Ontario Objective mg/L
4-Nitrophenol	.00	1.60	.13	ug/L	.00		
Aluminum	180.00	500.00	312.50	ug/L	1.82		
Ammonia plus Ammonium	.00	9.80	.80	mg/L	4.67	0.80	10
Arsenic	.00	38.00	9.50	ug/L	.06		
Benz(a)anthracene	.00	.29	.04	ug/L	.00		
Benzene	.00	.80	.01	ug/L	.00		
Benzo(b)fluoranthene	.00	.40	.03	ug/L	.00		
Benzobutylphthalate	.00	12.00	1.14	ug/L	.01		
Bis(2-ethyhexyl) phthalate	.00	2.40	.72	ug/L	.00		
COD	30.00	99.00	60.92	mg/L	355.49	60.92	200
Chloroform	.00	1.30	.69	ug/L	.00		
Chromium	.00	550.00	244.32	ug/L	1.43	0.244	1
Chromium (hexavalent)	6.60	6.60	6.60	ug/L	.04		
Chrysene	.00	.43	.07	ug/L	.00		
Copper	.00	30.00	6.08	ug/L	.04	.006	1
Cyanide Total	.00	.01	.01	mg/L	.06		
DOC	3.00	79.00	17.30	mg/L	100.95		
Di-n-butyl phthalate	.00	1.20	.38	ug/L	.00		
Hydrogen ion (pH)	6.57	8.80	7.82				
Indeno(1,2,3-cd)pyrene	.00	.86	.07	ug/L	.00		
Mercury	.00	.13	.01	ug/L	.00		
Methylene chloride	.00	3.20	.62	ug/L	.00		
Nickel	.00	29.00	2.42	ug/L	.01	0.002	1
Nitrate + Nitrite	1.00	2.70	2.18	mg/L	12.72		
Oil and Grease	.00	15.00	1.72	mg/L	10.04	1.72	10
Phenolics (4AAP)	.00	33.00	5.80	ug/L	.03	0.006	0.02
Sulphide	.00	.65	.23	mg/L	1.34		
TOC	6.00	83.00	21.04	mg/L	122.78		
Tetra-alkyl lead (Total)	19.00	19.00	19.00	ug/L	.11		
Total Kjeldahl Nitrogen	1.70	3.60	2.25	mg/L	13.13		
Total Phosphorous	.04	1.26	.30	mg/L	1.75		
Total Suspended Solids	6.00	41.00	16.75	mg/L	97.74	16.75	15
VSS	.00	25.00	9.03	mg/L	52.69		
Vanadium	.00	3.00	.72	ug/L	.00		
Zinc	10.00	1010.00	437.21	ug/L	2.55	0.437	1

Avg daily process flow 5,835.367 m^3/day

6.9 Comparison of Process Effluent Quality With Ontario Effluent Quality Objectives (OEQO)

During the 1989 MISA monitoring program all of the parameters included in the OEQO for Refineries (See Section 4.2) were monitored. Lead was monitored 3 times per quarter but it was not detected. The objective for suspended solids was exceeded. The maximum values for oil and grease, phenols total suspended solids and zinc were exceeded on occasion. The monthly wastewater tests showed no acute lethality to Rainbow Trout.

6.9.1 Comparison with U.S. EPA BPT/BAT Limitations (see Table X)

During 1989 the following number of exceedences would have occurred if the U.S. EPA limitations had been applicable.

Daily maximum limits	• Total Suspended Solids	12
	• Oil and Grease	1
	• Total Chromium	4
	• Sulphides	46
30 day average limits	• Total Suspended Solids	5
	• Sulphides	9
	• Total Chromium	9

6.10 Fundamental Factors Affecting Effluent Quality

This plant is fairly new and was built to modern standards. The sewers are well segregated and the plant is exceptionally well maintained.

Operators undergo formal training before they are allowed to operate the treatment plant. Written tests are used to evaluate their understanding of the equipment and processes. Early in 1991 all operators will attend formal instruction at Lambton College using the new operator's training manual developed by CPPI as a basic text.

The low sulphur content of the feedstocks combined with their high API gravity tend to reduce oil emissions from the desalter thereby reducing the amount of difficult to treat emulsified oil.

The cooling towers operate at very high cycles of concentration thereby minimizing the volume of blow down which must be treated in the wastewater system. In addition the towers are capable of running at a temperature differential of 13C° (23F°) thereby reducing the amount of blow down required to maintain chemical equilibrium in the system.

The absence of heavy oil cracking processes also reduces the amount of phenols, sulphides, ammonia and other contaminants which must be removed. The volume of process wastewater is low compared with older plants but not as low as might be expected from a plant of this age. Compared with Federal Regulations and Guidelines for new plants built since 1974 the ratio of process wastewater to feedstock is slightly below the regulation.

All of the stripped sour water is used by the desalter. Whereas the usual amount of wash water used in a desalter is about 5% of the crude volume, this plant uses 10%. This doubles the amount of dirty desalter water which must be treated later in the system, but of course does not change the overall volume.

The tank compounds in this plant are largely grassed. This is not a common practice. Grassing seems to be a good approach because it reduces the amount of storm run off due to absorption into the ground. It also creates a much neater appearance removing the need to sterilize the dyke walls using toxic chemicals. The water is carried away in subsurface drainage tiles which not only reduce the danger of spreading fire throughout the plant, but also improves housekeeping and appearance.

6.11 Control Orders

There are no outstanding control orders in effect.

6.12 Capital and Annual Operating Costs for Wastewater Treatment System

Approximately $30 million has been spent in wastewater treatment equipment since the plant went on stream in 1978. Major cost items are a new landfarm and MISA monitoring equipment.

The relatively low spending on capital cost items is due mainly to the fact that the plant was built in 1978 and has required relatively few changes since then.

Operating costs for labour., utilities, chemicals, and maintenance are about $2.4 million per year.

6.13 Best Management Practices

6.13.1 Training

The operators must undergo a formal training program consisting of five modules. In class training and tests are important parts of the curriculum. The program teaches the operators the basics in biological treatment. The training was based on input from operators as to what knowledge is required in order to adequately perform their job. Presently Nova is preparing videotapes in order to illustrate key concepts.

A wastewater operators course at Lambton College is expected to be in effect by the beginning of 1991. This course will be mandatory for all wastewater treatment operators.

6.13.2 Manuals

A plant operating manual outlines basic principles, and provides guidance in areas such as upsets, spills, and emergencies.

There is also a sewer manual which traces all sewer lines back to their individual drains.

6.13.3 Specifications

Operating targets are set for each unit in the wastewater treatment plant. Some rough testing of streams is done in the field by the operators to determine whether the specifications are being met. Further to this analysis is performed in the main laboratory.

Inlet streams to each unit are monitored in order to deal with unexpected changes in the system.

There is a laboratory dedicated to the treatment of wastewater.

6.13.4 Responsibility/Authority

A flat organizational structure exists at the plant. Only two levels of employees exist between the manager and the technical staff. The shift superintendent has a role similar to the plant manager. The shift leader can bypass the shift superintendent if necessary. The shift superintendent is responsible for calling in spills to the ministry.

Employees who have a part-time responsibility for water treatment include:

- shift leader;
- operations technical assistant;
- day operator;
- area process engineer;
- operations superintendent;and
- a number of other part-time people.

6.13.5 New Projects

Ideas for new projects are originated through team meetings. At these meetings the environmental needs are identified. A checklist is filled out to determine the percentage of the project that is environmental. The request for engineering assistance triggers a response for the project.

All maintenance is prioritized in the work order system as either urgent, emergency, or normal. Safety, health and environment receive the highest priorities

There is a one year plan for upgrading of wastewater treatment facilities. The WETS team developed a detailed five year plan for upgrading and replacing equipment.

6.13.6 Oil Spills in Plant

Two vacuum trucks are available for cleaning of spills. Dumpster buckets are available throughout the plant for minor spills. The floor of the tank dykes is below the ditch level, therefore spills can only drain to a sewer line. All spills are reported to the ministry no matter how small they may be. In 1989 no liquid spills were reported to the Ministry of the Environment.

6.13.7 Landfarming

An adequate, fenced in, landfarm exists on the site. Every load discharged to the landfarm is recorded and must receive prior approval from the environmental section. Specific materials are not allowed to go to the landfarm. Eleven monitoring wells exist at the landfarm. Three monitoring wells were required by the Ministry of the Environment.

6.14 CONCLUSIONS

This is a modern plant with good management practices and fairly new equipment. Operators must meet high standards of proficiency before they are allowed to operate alone. More formal training will commence in 1991.

The plant is completely on recirculated cooling water with negligible air cooling. The cooling towers operate at exceptionally high cycles of concentration and temperature drop.

The absence of heavy oil cracking units and the use of high API gravity low sulphur feedstocks makes the task easier than in a normal refinery with a full slate of process units. This set of circumstances results from the purpose of the plant namely to prepare feedstocks for the petrochemical industry not to market a full slate of petroleum products.

The exceedences reported in Section 6.9 occurred only occasionally and were not of a large magnitude. With exception of total suspended solids which seems to be a problem area the average values for the year were well within the limits.

6.15 APPENDIX

- chemical used
- process flow schematic
- waste water schematic

CHEMICALS USED

Storage and Handling

Name	*Main Chemical Ingredient*
Alumina	Aluminum Oxide
Benzene	Benzene
DYE D390	Aliphatic hydrocarbons
Brine	Sodium chloride and water

Chemical Laydown Area

ALCHEM 17020	Organic amines
ALCHEM 71D5	Fatty acid/polyglycol mixture
ALCHEM 5C91	Alkyl benzenes and naphthalenes
Dupont AO22	Antioxidant (phenylene diamine)
Chlorine	Chlorine
ALCHEM 5B11	Amine mixture (hydrazine)
ALCHEM 5B15	Aromatic hydrocarbons in naphtha carrier
ALCHEM 7370	Zinc, hexavelant chromate
ALCHEM 5E41	Aromatic hydrocarbon
BETZ AF114	Alkylated succinamide in heavy naphtha
ALCHEM 19H	Hydrazine
ALCHEM 7387	Potassium phosphonate and water
Kerosene	Kerosene
Methanol	Methanol
Mineral Spirits	Mineral Spirits
ALCHEM 8103	Cationic flocculent
PROCHEM 4H1	Amino alcohol
BETZ WS-66	Mea and ethylene diamine
Phosphoric acid	H_2so_4
BETZ 2068	Heavy aromatic naphtha
Santicizer cleaner	Solvent
Toluene	Toluene

Warehouse

Antifreeze	Glycol
Boiled linseed oil	Linseed oil
Lubricant	Oil

Bulk Warehouse

Amoco 158	Organic sulphur compound
MEA	Monoethanolamine
OAKITE 220NP	Sodiumsilicate salt solution
BETZ 5704	Polyphosphate and sodium sulphites solution
Lubricant	Oil
Mix. bed dowex	Ion exchange resins
Strong acid-amberlite	Ion exchange resins
Weak acid-amberlite	Ion exchange resins

Process Units

Crude

ARI 100XSL	Catalyst-cobalt phthalolcyanine sulfonate
Desalter sludge	Water, solids, oil
Desalter water effluent	Water, sulphide, oil & grease, chlorides, BOD
BETZ PROCHEM 4H1	Amino alcohol
ALCHEM 5B11	Amine mixture (hydrazine)
ALCHEM 5B15	Aromatic hydrocarbons in heavy naphtha carrier
Tetrolite tolad 511 (antistatic)	Acylated amines, aromatic hydrocarbons

Olefins

ALCHEM 5C91	Alkyl benzenes and naphthalenes
BETZ A[58-4	Water, polyphosphate & sodium sulphites
Methanol	Methyl alcohol
Monoethanolamine (MEA)	Monoethanolamine
Spent caustic neutralized	Caustic soda, sulphides, hydrocarbons
BETZ Petromeen WS-77	MEA & Ethylene diamine
BETZ 2068	Heavy aromatic naphtha
BETZ AY22	Heavy hydrocarbon
H_2so_4	H_2so_4 (Sulphuric acid)
DMDS	Dimethyldisulphide
Prochem AF114	Alkylated succinamide in heavy aromatic naphtha
Catalyst	Palladium on alumina chrome-moly on alumina CuO on alumina

DPG

Activated carbon	Carbon granules
Clay	Fullers earth
Dupont A022	Antioxidant (phenylenediamine)
Tetraethylene glycol	Tetraethylene glycol
M.E.A.	Monoethanolamine
Antifoam-Dow Corning 1500	Silicone oil
Caustic	Caustic soda NaOH
DMEA	Dimethylethanolamine

Utilities

ALCHEM 19-H	Hydrazine
ALCHEM 98103	Cationic flocculent
Anion resin	Polystyrene-divinyl benzene (inert plastic)
Cation resin	Sulphonated polystyrene & divinyl benzene
Chlorine	Chlorine
BETZ 2023	Phosphate & dispersant
BETZ slimicide 242	Dodecylquanidine acetate
BETZ slimicide C-30	Bis (trichloromethyl) sulfone, methylene, bisthiocyanate
BETZ 407C	Ethyl alcohol & dispersant
BETZ foam-trol 300-85L	Mineral oil & surfactant
BETZ 26104	Sodium hydroxide
ALCHEM 7387	Potassium phosponate, water
ALCHEM 7370	Zinc, chromate in acid solution
ALCHEM 7330	Biocide solution
ALCHEM 7313	Hydrocarbon dispersant

Wastewater Treatment

ALCHEM 7105	Fatty acid/polyglycol mixture
Phosphoric acid	H_3PO_4
Urea	Urea
Alum	Alum (aluminum sulphate)

Lab

Mercury	Mercury
Toluene	Toluene
Acetone	Dimethyl ketone

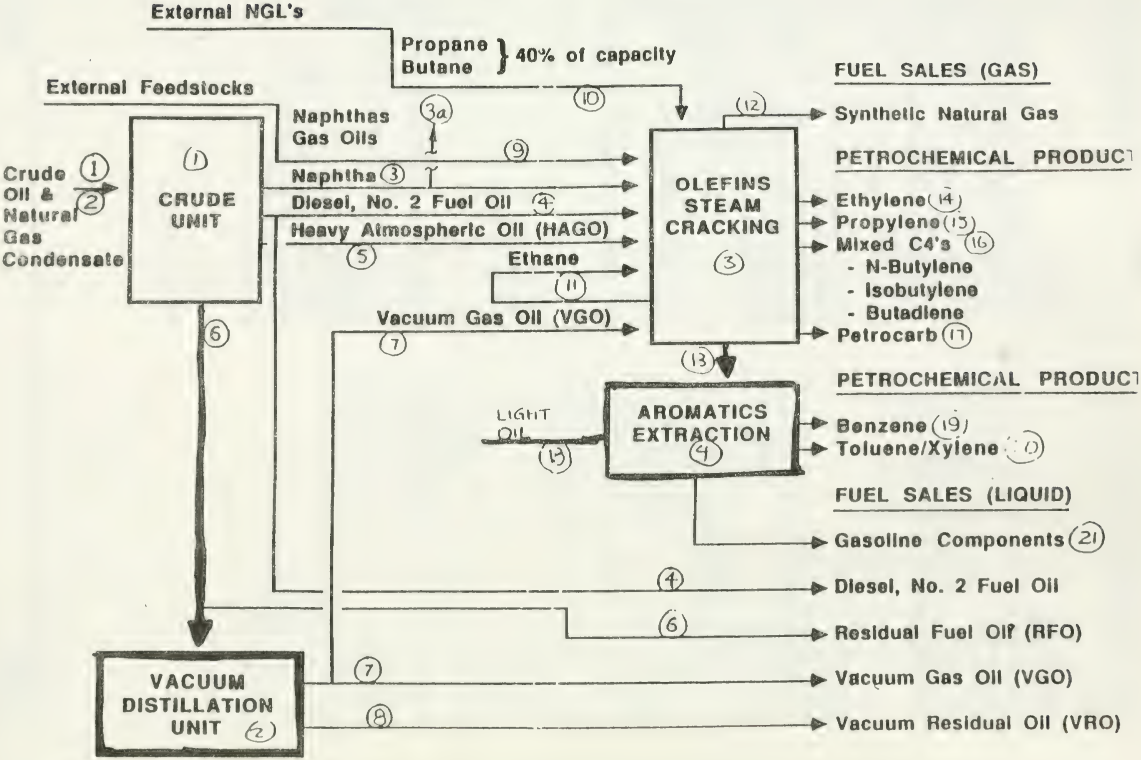
Maintenance

Alkaline cleaner	Sodium hydroxide, sodium carbonate in water solution
Citrosolve	Citric acid solution
Ethylene glycol	Glycol-antifreeze
Varsol	"Mineral spirits"
ALCHEM 8890 CLEANER	Solvent (halogenated hydrocarbon)
"OAKITE" 220 NP	Water solution-sodium silicate salts surfactants, ionic detergent
Safety solvent/degreaser	1,1,1 trichloroethane
ALCHEM 8960	Degreaser

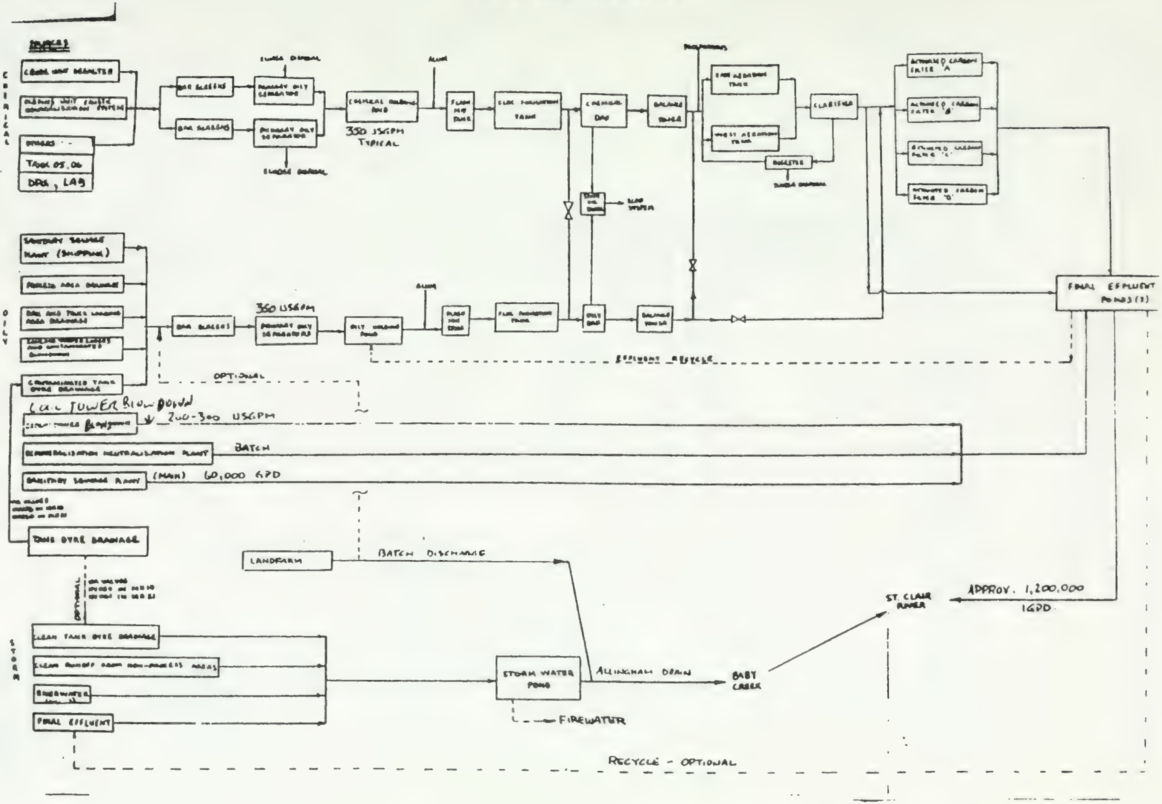
Miscellaneous

Brine	Salt water (NaCL)

NOVA PETROCHEMICALS PROCESS



NOVA PETROCHEMICALS



7.0 CURRENT STATUS OF SHELL CANADA'S SARNIA REFINERY

7.1 Plant Description

Shell Canada is located in Sarnia, Ontario and has been in operation since 1952. At this particular site there is a refinery and a petrochemical plant. The saleable products produced at the refinery are:

- benzene;
- toluene;
- xylene;
- diesel fuel;
- propane;
- butane;
- stove oil;
- furnace oil;
- hydrogenated aliphatic solvents;
- isopropyl alcohol;
- polypropylene nibs (chemical plant);
- gasolines;
- bunker fuel;
- sulphur'
- aromatic solvents;
- naphtha mix.

7.1.1 Refinery Process Data

Note: All data is in M^3/day

Process		1989 Stream Day Capacity	1989 Calendar Day Rate	Year Installed
Atmospheric Crude Distillation	No.1	5,100	4,560	1952
	No.2	6,700	5,210	1974
Crude Desalting		11,800	9,785	1952/1974
Vacuum Tower	No.1	1,700	1,550	----
	No.2	2,500	1,900	
Viscosity Breaking		900	550	1961
Fluid Cat. Cracking		2,800	2,467	1952
Hydro Cracking		1,400	1,070	1971
Catalytic Reforming		1,900	1,190	1972
Hydrogen Treating	NHT	3,200	2,350	1971
	DHT	1,210	430	1960
Catalytic Polymerization		240	330	1954
Total Sweeting Process		4,710	3,000	
Aliphatic Solvents (SHU)*		480	160	1983
Aromatic Solvents **		1,000	40	1959
BTX Extraction (UDEX)		1,350	1,100	1959
Hydrodealkylation (Toluene to Benzene)		100	60	1961
Gas Recovery		2,800	2,470	1961
Other BTX-I		950	830	1959
BTX-II		1,030	860	1971
Naphtha Distillation **		1,000	390	1959
Diesel Oil Absorber (unsats)		800	640	1983
C3/C4 Absorber (sats)		640	400	1983
Fuel Gas Absorber M^3/day		0.58×10^6	0.28×10^6	1981
Propylene Feed Prep Unit		1,400	1,145	1979
Polypropylene Plant		900	350	1979
Isopropyl Alcohol Plant		560	300	1979

* Unit "production" rate, not charge.

** Aromatic solvents and naphtha distillation share common distillation unit on "blocked out" operation.

The total feedstock charged in 1989 was 10,400 M^3/day composed of 9,770 M^3 of crude to the refinery and 630 M^3 of other feeds to the Chemical Plant (propylene, naphtha, raffinate, etc).

7.2 Feedstocks Processed in 1989

In 1989 the refinery ran a variety of feedstocks only 4 of which were crudes.

Name	% Run	% Sulphur	API Gravity
I.P. Sweet Alberta	70.0	0.36	38.4
Midale Saskatchewan	13.0	2.1	28.6
I.P. Sour Alberta	1.0	1.1	31.5
Lt. Sour Blend Alberta	1.0	1.25	34.8
Naphtha (Nova)	3.0	300 ppm	64.5
Raffinatte (Nova)	2.0	--	62.0
Propylene (Nova)	10.0	--	--

7.3 Chemicals Used

See appendix in Section 7.15.

7.4 Water Management

7.4.1 Water Supply

Approximately 265,000 $M^{3/day}$ of fresh water is pumped from the St. Clair River. 65,000 M^3/day of this is pumped to the adjacent Ethyl Corporation.

Water is used mainly for cooling, washing and stripping operations, and steam generation. Domestic water needs are purchased from the municipality.

7.4.2 In Plant Reuse and Recycling Techniques

The Chemical Plant, built in 1978, is integrated with the refinery insofar as utilities and wastewater treatment are concerned. This plant uses only recirculated cooling water and recirculates about 200,000 M^3/day at 6-8 cycles of concentration.

The refinery uses once through cooling water at a flow rate of 180,000 M^3/day.

Approximately 80 M^3/day of #1 crude condensate is used in #1 crude desalter, and 250 M^3/day #2 crude condensate is used in #2 crude desalter. This reuse comprises 80% of the desalter needs. These condensates are not stripped. A total of 650 M^3/day of sour water is stripped and sent to the wastewater treatment plant. Steam condensate is collected and returned where economically possible.

7.4.3 Ratio of Wastewater to Feed Charge

The total volume of wastewater is approximately 13,300 M^3/day, of which about 15% or 2000 M^3/day comes from the Chemical Plant operation. The net amount is therefore approximately 11,300 M^3/day from the refinery.

The rate of wastewater produced by the refinery/chemical plant complex in 1989 was 1279 M^3 of wastewater for each 1000 M^3 of total feedstock charged. If the 15% contribution of the chemical plant is deducted the rate is 1155 M^3 per 1000 M^3 of feedstock run by the refinery.

In terms of Canadian gallons per barrel of feedstock the rate is 44.7 for the complex and 40.5 for the refinery alone.

Using Federal Regulations and Guidelines for Petroleum Refineries the ratio of wastewater production is 31.1 Canadian gallons per minute per 1000 BPD of total feedstock for the complex and 28.1 for the refinery alone. Federal Regulations and Guidelines are based on 20 Canadian gallons per minute/1000 BPD for new refineries or additions thereof and 40 for existing plants. This plant can be considered a moderate water user.

7.4.4 Cooling Methods Used

The refinery is cooled by a mix of once through cooling water and air cooled exchangers. The Chemical Plant is 100% cooled by recirculated water through cooling towers and localized closed cooling systems. Air cooling accounts for about 25% of the refinery cooling duty. In 1989 the Chemical Plant used zinc-chromate based chemicals for recirculated water treatment.

7.5 Segregation of Sewer Systems

The sewers are segregated into five systems:

1. *Process Wastewater*

   This sewer system includes vessel and tank drainings, sour water stripper bottoms, ballast waters pad drainage, cooling tower blowdown, storm water falling on unit areas and other contaminated process waters.

2. *Potentially Contaminated Once Through Cooling Water (OTCW)*

   This system contains wastewater from once through cooling water where the pressure of the cooling water in the heat exchanger is lower than the pressure of the hydrocarbons being cooled. Thus the oily side can leak into the cooling water. This water includes blowdown from water treatment and boiler blowdown and is treated through the API separator.

3. *Uncontaminated Once Through Cooling Water*

   The once through system also includes a subsystem where the pressure of the cooling water is higher than the hydrocarbon side. Thus the water will leak into the oil side. This cooling water is discharged directly to Talford creek.

4. *Storm Water*

   The storm water system collects runoff from roads, ditches, landfarm, the tank farm dyked areas and concrete pads in process areas.

5. *Sanitary Wastewater*

   All sanitary sewer water is routed to the septic tank and then pumped directly into the aeration basin of the biotreater.

Presently the sewer systems are 98% segregated. Since the site is almost 40 years old, interconnections between the systems are still being identified. However, an active ongoing program is aimed at achieving 100% segregation.

7.6 Sources of Wastewater

The total volume of process wastewater as measured by the MISA program in 1989 averaged 13292 M^3/day. Approximately 15% of this water originated in the Chemical Plant.

The bulk of the process water comes from numerous sources within the process units. However a number of small specific sources have been identified and are listed below because they may offer some opportunities for reduction.

	M^3/day	Source
Pump glands	1500	Refinery
Ballast water	550	Refinery
Storm water	150	Refinery & Chemical Plant
Cooling tower blow down	400	Chemical Plant
Desalters	488	Refinery
Stripped sour water	650	Refinery
Catalytic Reformer scrubber	77	Refinery
Chemical Plant miscellaneous	1600	Chemical Plant
Other (Corrosion control, DEW unit)	650	Refinery

In addition to the above selected sources 250 M^3/day of wastewater from the water treatment system and another 600 M^3/day from boiler blow down are discharged into the once through cooling water. These streams contain inorganic chemicals normally present in the river water but at higher concentrations.

7.7 Opportunities to Reduce Wastewater Flow

Further study is needed to determine the possibility of reducing the volume of some of these selected wastewater sources. The following suggestions are offered for follow up.

- Pump glands - consideration should be given to a closed cooling system similar to that used by a few modern refineries. The system can be likened to that used to cool an automobile engine.
- Stripped sour water - attempts should be made to reuse or recycle this solids free water. Some might be used for cooling tower make up or for make up to the Catalytic Reformer scrubber.

7.8 Description of Wastewater Treatment System

7.8.1 Discussion of Schematic

The wastewater treatment system is illustrated in Section 7.15.

The process wastewaters and storm waters are each fed into one of two round oil/water separators. Free oil floats to the surface of the separator where it is removed and sent to the refinery slop oil system to be recycled in the crude distillation units. Solids collect in the bottom of the separators and are cleaned out approximately every 5 years.

The water is combined with ballast water then sent to the dissolved air flotation unit where emulsified oil and suspended solids are further removed. This stream is combined with process water, storm water, and cooling tower blowdown from the chemical plant. This total stream is then sent to an equalization basin prior to biological oxidation. From the equalization tank the water flows to the aeration tank where recycled micro-organisms from the clarifiers are added. Oxygen required by the micro-organisms is provided by five surface mechanical aerators. Effluent from the biological oxidation unit is sent to three parallel clarifiers where the micro-organisms settle out and are pumped to the aeration tank as recycle. The clarified water is discharged to Talfourd Creek via the potentially oily water separator or directly.

A portion of the recycled sludge flow from the clarifiers is wasted in order to maintain 2000-2500 MLSS in the aeration basin. The wasted sludge stream is fed into an aerobic digester and aerated. Overflow from the digester is fed to the water treatment system. The digested sludge goes to a sludge thickening tank and then to a belt filter press. The cake goes to a landfarm. The filtrate is returned to the treatment system.

Potentially oily once through cooling water from heat exchangers is passed through a rectangular API gravity separator and then discharged to Talfourd Creek. A sensor on the inlet to the separator signals an alarm if a sheen appears.

Uncontaminated, i.e. higher pressure clean cooling water is discharged directly to Talfourd Creek.

Sanitary sewer waste is routed to the septic tank and then pumped directly into the aeration basin of the biotreater.

All of the Chemical Plant effluent including storm water normally goes to the refinery treatment system via the equalization basin after primary separation.

Dioxins have been detected in the 20° Be caustic solution used in the scrubber to absorb or react with the off gases from the reactors during the regeneration of the reforming catalysts. The caustic phase is passed through a bed of activated carbon to remove the dioxins. The filtrate then goes to the wastewater treatment plant. The carbon goes to Tricil for secure landfill. In 1989 40 samples of treated effluent revealed no dioxins present.

7.8.2 Sampling and Monitoring Frequency

The biological oxidation unit effluent is tested four times per day for suspended solids, ammonia, pH, phenolics, and sulphides.

PH is measured on the potentially oily water separator inlet stream continuously.

The three outfalls include the uncontaminated once through cooling water, potentially oily water, and the effluent from the biological oxidation unit. The flow on each outfall is monitored.

7.8.3 Summary of MISA Process Effluent Results for 1989

The following data are results from the 12 month Misa monitoring program.

Priority Pollutants Found in Process Effluent
Shell Canada Products Limited (Sarnia)
MISA Monitoring Data Dec 88 to Nov 89

Parameter	Min	Max	Avg	Unit	Loading Kg/day Avg	Avg Concen. 1989 mg/L	Ontario Objective mg/L
1,2-Dichloropropane	.00	27.00	2.57	ug/L	.03		
Aluminum	220.00	2700.00	1175.83	ug/L	15.63		
Ammonia plus Ammonium	.00	16.90	.31	mg/L	4.12	0.31	10
Antimony	.00	14.00	1.17	ug/L	.02		
Arsenic	.00	13.00	3.08	ug/L	.04		
Benzene	.00	82.22	1.01	ug/L	.01		
Benzo(b)fluoranthene	.00	2.60	.22	ug/L	.00		
Benzylbutylphthalate	.00	1.10	.09	ug/L	.00		
Bis(2-ethylhexyl) phthalate	.00	1.60	.13	ug/l	.00		
COD	13.00	110.00	49.83	mg/L	662.36	49.83	200
Chromium	.00	150.00	17.95	ug/L	.24	0.018	1
Cobalt	.00	21.00	6.00	ug/L	.08		
Copper	.00	11.00	4.17	ug/L	.06	.004	1
Cyanide Total	.00	.02	.01	mg/L	.13		
DOC	3.00	256.00	18.81	mg/L	250.03		
Ethylbenzene	.00	8.97	.14	ug/L	.00		
Hydrogen ion (pH)	6.40	8.80	7.71				
Nickel	.00	10.00	.83	ug/L	.01	0.00083	1
Nitrate + Nitrite	.00	.35	.11	mg/L	1.46		
Oil and Grease	.00	15.00	3.38	mg/L	44.93	3.38	10
Phenanthrene	.00	.35	.03	ug/L	.00		
Phenol	.00	1.90	.16	ug/L	.00		
Phenolics (4AAP)	.00	70.00	6.45	ug/L	.09	0.0065	0.02
TOC	4.00	308.00	27.09	mg/L	360.09		
Tetra-alkyl lead (Total)	15.00	15.00	15.00	ug/L	.20		
Toluene	.00	24.80	.81	ug/L	.01		
Total Kjeldahl Nitrogen	.26	4.90	1.78	mg/L	23.66		
Total Phosphorus	.00	3.23	.49	mg/L	6.51		
Total Suspended Solids	.00	1038.00	64.66	mg/L	859.48	64.66	15
VSS	.00	666.00	38.39	mg/L	510.29		
Vanadium	.00	28.00	7.00	ug/L	.09		
Zinc	.00	800.00	32.97	ug/L	.44	0.033	1
m-Xylene + p-Xylene	.00	42.86	.75	ug/L	.01		
o-Xylene	.00	16.80	.25	ug/L	.00		

Avg daily process flow 13,292.297 m^3/day

7.9 Comparison of Process Effluent with Ontario Effluent Quality Objectives (OEQO)

During the 1989 MISA monitoring program all of the parameters included in the OEQO for Refineries (See Section 4.2) were monitored. The maximum permissible values for ammonia, oil and grease, phenolics and total suspended solids were exceeded. The annual average value for the latter parameter was 2 to 3 times higher than the set limits. Monthly tests revealed no acute lethality to Rainbow Trout.

7.9.1 Comparison with U.S. EPA BPT/BAT Limitations

During 1989 the following number of exceedences would have occurred if the U.S. EPA BPT/BAT limitations had been applicable.

Daily maximum limits	• Total Suspended Solids	294
	• Oil and Grease	25
	• Sulphides	2
30 day average limits	• Total Suspended Solids	12
	• Oil and Grease	3
	• COD	1

7.10 Fundamental Factors Affecting Effluent Quality

This is a highly integrated complex plant employing process units some of which are 30-40 years old. Originally, they were built as state of the art but standards of performance have changed drastically since that time. The wastewater treatment system however employs classical treatment methods in current use.

There is a large degree of variability in the effluent quality, particularly with respect to total suspended solids. This large variability seems to be related to the operation of the biological oxidation unit. The ratio of the volatile suspended solids to the total suspended solids remains fairly constant and seems to bear this out.

The treatment system is called upon to treat a mixture of refinery and chemical plant effluents. This can cause problems since some of the chemicals from the Chemical Plant are water soluble and can cause floc settling difficulties.

The feedstocks, are relatively low in sulphur with a high gravity. These factors tend to ease the difficulty of wastewater treatment.

The refinery is cooled by once through water and air while the Chemical Plant uses recirculated cooling water and air cooling. Refinery heat exchangers are therefore sized for a 22C° (40F°) increase in water temperature versus 11C° (20F°) for cooling towers. Replacement of these exchangers with new exchangers almost twice the size would be required to accommodate a recirculated water system. Once through water cooling requires no blow down thereby reducing the volume of process wastewater.

7.11 Control Orders Issued

There are no outstanding control orders.

7.12 Capital Costs for Wastewater Treatment System

The following is a list of capital costs incurred for wastewater treatment since 1964. All costs are in dollars for that year.

Year	Item	Amount $	Inflate	Total 1988 $
1964	Tankage	60,000	6.62	397,200
1965	Collection system	100,000	6.39	638,600
1968	API separators	500,000	5.49	2,745,000
1969	DAF	206,000	5.07	1,044,832
1972	Biotreater	650,000	3.90	2,531,750
	Clarification	225,000	3.90	876,375
	Sour water stripper	875,000	3.90	3,408,125
1974	Collection System	20,000	3.12	62,460
1975	Collection System	34,000	2.65	90,168
1976	Collection System	5,419,000	2.05	11,098,112
	Flow measure/sampler	42,000	2.05	86,016
	Cooling tower	5,785,000	2.05	11,847,680
1978	Flow measure/sampler	15,000	1.94	29,070
	Collection System	23,000	1.94	44,574
1983	Landfarm	180,000	1.17	209,880
1986	API Separators	7,000	1.04	7,294
	Storm Pond	500,000	1.04	521,000
1987	Storm Pond	2,554,000	1.02	2,597,418
	Biotreater	217,000	1.02	220,689
	Clarification	850,000	1.02	864,450
	Dewatering	1,200,000	1.02	1,220,400
	Tankage	300,000	1.02	305,100
	Miscellaneous	178,000	1.02	181,026
1988	Flow Measure/Sampler	375,000	1.00	375,000
	Collection System	1,725,000	1.00	1,725,000
	API Separators	1,925,000	1.00	1,925,000
Total Installed Cost		23,965,000		45,052,219
Escalated to $1988		45,052,219		
Escalated to $1989			1.04	46,854,308

Annual operating costs for 1989 were reported to be $1,764,000. This includes labour, chemicals, utilities and maintenance.

7.13 Best Management Practices

7.13.1 Training

All employees in the plant area must go through a basic training program. This training is an orientation program for safety, health, and environmental practices. The training is performed on the job as well as in class.

Refinery operators undergo process unit training. The trainee covers individual unit training via unit training modules, and "one on one" training on the unit with an experienced operator.

Wastewater treatment operators receive primarily on the job training. The area operator and foreman are responsible for this training.

The existing training procedure for wastewater treatment operators will be altered significantly in February, 1991. Formal classroom training at Lambton College will be provided for wastewater treatment plant operators.

7.13.2 Training Manuals

All process units have manuals which are kept up to date. These manuals outline the steps the operator should take if an upset occurs. These manuals are written by Shell employees.

A manual has been produced for the wastewater treatment operators by CPPI and will be used as the basis for the Lambton College classroom training.

7.13.3 Specifications

Specifications exist for the operators to enable them to deal with process upsets, start-up, shut-down, and power failures. Specifications also exist for the final effluents and on the biological oxidation unit. Operating guidelines for conventional pollutants are provided for the biotreater feed. These guidelines are regularly being updated and revised.

7.13.4 Responsibility/Authority

Responsibility is provided through a line function with staff support. The shift foreman is in charge of the dispatching area operators, who work in the control room. Effluent plant operators, who generally work outside, report to the dispatching area operators.

Many people have a full and part-time responsibility for water treatment. They include the:

- senior process engineer -environmental & technical support;
- wastewater treatment coordinator - dispatching, operations support;
- senior operations engineer - dispatching, operations support;
- MISA coordinator - environmental;
- dispatching day supervisor - dispatching;and
- dispatching manager - environment manager.

7.13.5 New Projects

Every new project must go through a health and environmental review process. Each project must be approved by the environmental manager before being estimated.

The repair of wastewater treatment equipment receives priority over other projects if it is likely to have a legal or effluent quality effect.

A large proportion of the capital budget is targeted for environmental concerns. A master plan exists for future environmental projects.

7.13.6 Oil Spills in Plant

Shell Canada Sarnia division has its own vacuum truck to clean up spills. A boom installed on Talfourd Creek can remove spills visible on the surface of the water. Pads are available for the absorption of oil. The Plant is also a member of the Blue Water Clean program which aids in the clean up of spills beyond the capacity of the refinery to handle.

In 1989 the plant reported 14 liquid spills to the Ministry of the Environment. Most of these were small spills of less than one litre into Talfourd Creek and were quickly boomed and removed before they could reach the river. One large spill of 3000 litres was entirely internal and did not reach the creek. Two occurred at the dock on the St. Clair River but were small in volume and quickly cleaned up.

7.13.7 Landfarming

There are 13 acres of land available for landfarming of sludges, however, only 7 are presently being used. The landfarm is not fenced off, but is protected by barriers to prevent entry. There is a list of wastes which can be distributed on the landfarm. The soil and five wells adjacent to the property are monitored. Leachate from the landfarm drains to the process sewers and is treated.

7.14 Conclusions

This refinery is relatively old and very complex with a once through cooling water system. The Chemical Plant is only 12 years old and is integrated with the refinery. The refinery treats all of the Chemical Plant water.

The water treatment system is modern and employs treatment modules commonly in use elsewhere. The effluent quality is good meeting all Ontario Effluent Quality Objectives for Refineries on an average basis, however total suspended solids is a continuing problem with occasional exceedences.

The amount of wastewater may be considered on the low side compared with Federal Guidelines, however the refinery does not employ cooling towers and therefore has no blow down in the effluent. The once through cooling water is closely monitored for hydrocarbon sheens, and these do occur from time to time. No dioxins or furans have been detected in the treated process effluent.

The plant employs a comprehensive monitoring program both in the process effluent and around the biological treater.

Treatment operators receive on the job training in an apprentice type system. Early next year operators will be enroled at Lambton College for more formalized training using the CPPI manual. The operators have a written manual based on the "What if" approach.

Since the plant discharges all its treated water into Talfourd Creek a very small spill quickly becomes apparent. This is not the situation with the other plants. The plant actively participates in the Blue Water Clean co-operative.

7.15 APPENDIX

- chemical used
- process flow schematic
- waste water schematic

CHEMICALS USED

#1 Crude Unit - PETROTECH 1200 (filming agent)
AQUEOUS AMMONIA
ANHYDROUS AMMONIA
MEROX WS (mercaptan removal)

Fluidized Catalytic Cracking Unit - MEROX WS (mercaptan removal)
PHOSPHORIC ACID
ANTHRACITE COAL
METAL DEACTIVATOR-2
DIETHANOL AMINE
CO PROMOTER
ZIMMITE 105
TILTER CEL (cellulose)
ETHYL ANTIOXIDE

Process 1 & 2 (ISOMAX) - SODIUM HYDROXIDE

Effluent Treatment - ALCHEM 603 (polyelectrolite)
KEDCHEM (polyelectrolite)
ISLS 9955 (polyelectrolite)
ALCHEM 8103 (polyelectrolite)

Dispatching - LUBRIZOL
SHELL ASA-350
DEACTIMINE 650
METHYL CARBITOL
ORANGE OIL DYE
GREEN DYE
ETHYL MMT
PHOSPHORIC ACID (biox nutrient)
METHANOL

Steam Plant - ALCHEM 156C
CALGON 2230
CALGON 2391
CHLORINE
CAUSTIC SODA FLAKE
SUPER FILAMEEN 3105
SODIUM CHLORIDE
817-PHOSPHATE/CARBONATE MIX
698-POLYMETHACRYLATE PHOSPHATE
66-SODIUM SULPHATE COBALT-SULPHATE MIX
VOS-68
ADAIR 500 SURFACANT
HYDRATED LIME
FERROUS SULPHATE
CALGONITE POLYMER EB4400

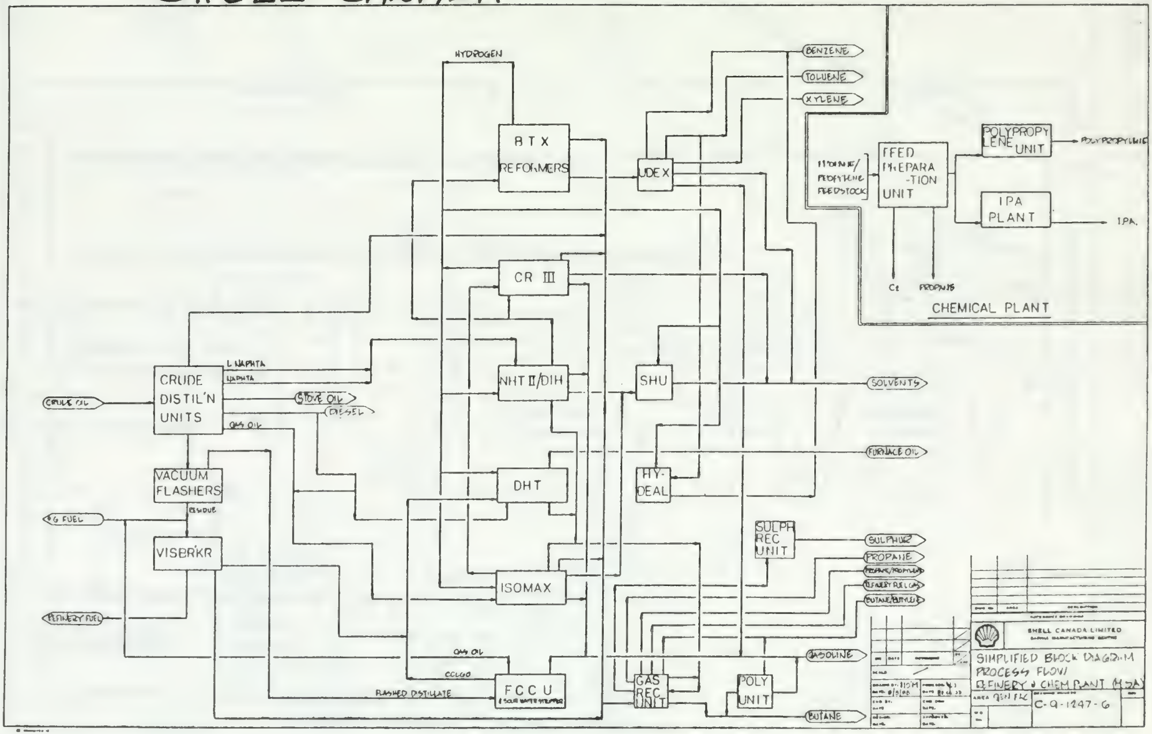
Refinery - VOS-68
ADAIR 500 SURFACANT

Polypropylene Unit
SULPHURIC ACID
SODIUM HYDROXIDE
PENTANE
N-BUTYL ALCOHOL
TITANIUM TETRACHLORIDE
TRI-ETHYL ALUMINUM CHLORIDE
DIETHYL ALUMINUM CHLORIDE
CHLORINE
SODIUM CARBONATE
SODIUM ACETATE
GLYCEROL MONOSTEARATE
CALCIUM STEARATE
BUTYLATED HYDROXYTOLUENE]
SODIUM BENZOATE
CALCIUM CAPRYLATE
NITROGEN
HYDROGEN
POLYMERIC HINDERED AMINE TRIS (2,4-DI-TERT-BUTYL PHENOL)-PHOSPHITE
CALCIUM (3,5-DI-TERT-BUTYL PHENOL) - PHOSPHITE
PHOSPHATE PENTAE NYTRITYL-TETRAKIS (3,3,5 DI-T-BUTYL-4-HYDROXYPHENOL) PROPIONATE

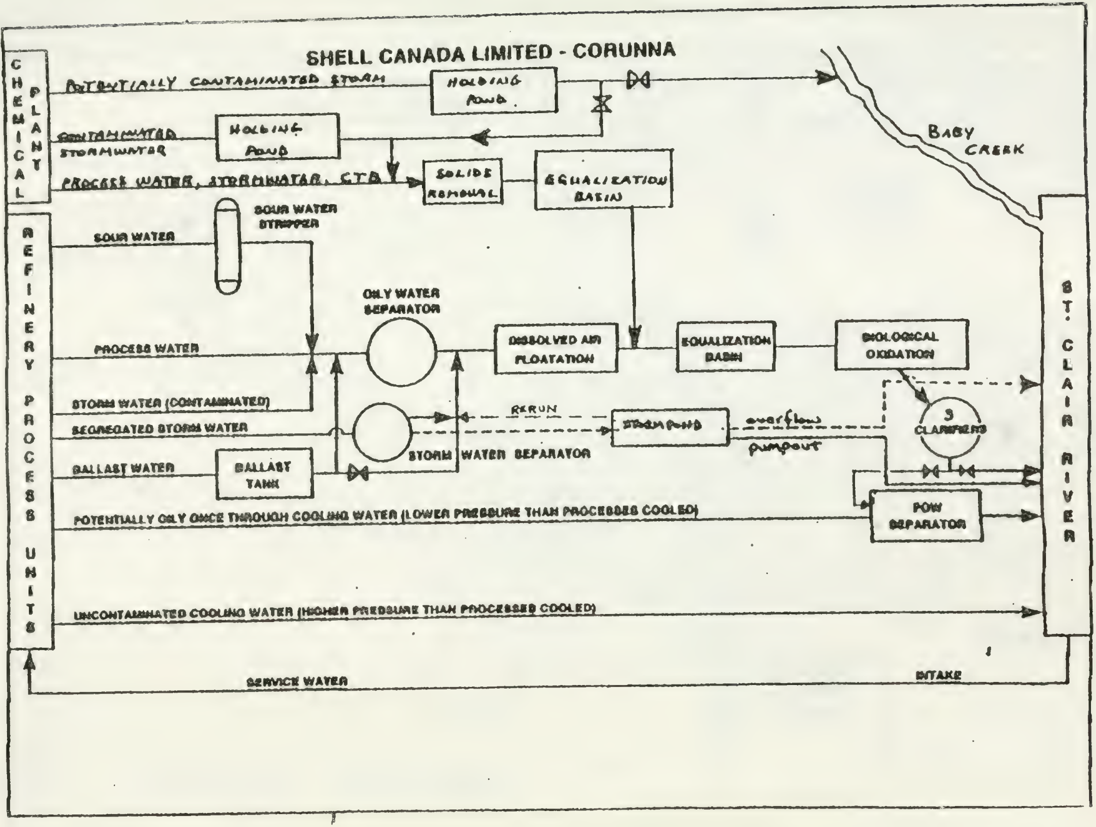
Isopropyl Alcohol Unit - ETHYLENE GLYCOL
SULPHURIC ACID
CHLORINE

Cooling Water (Refinery) - CHLORINE
ZIMMITE (anionic polyacrylamide)

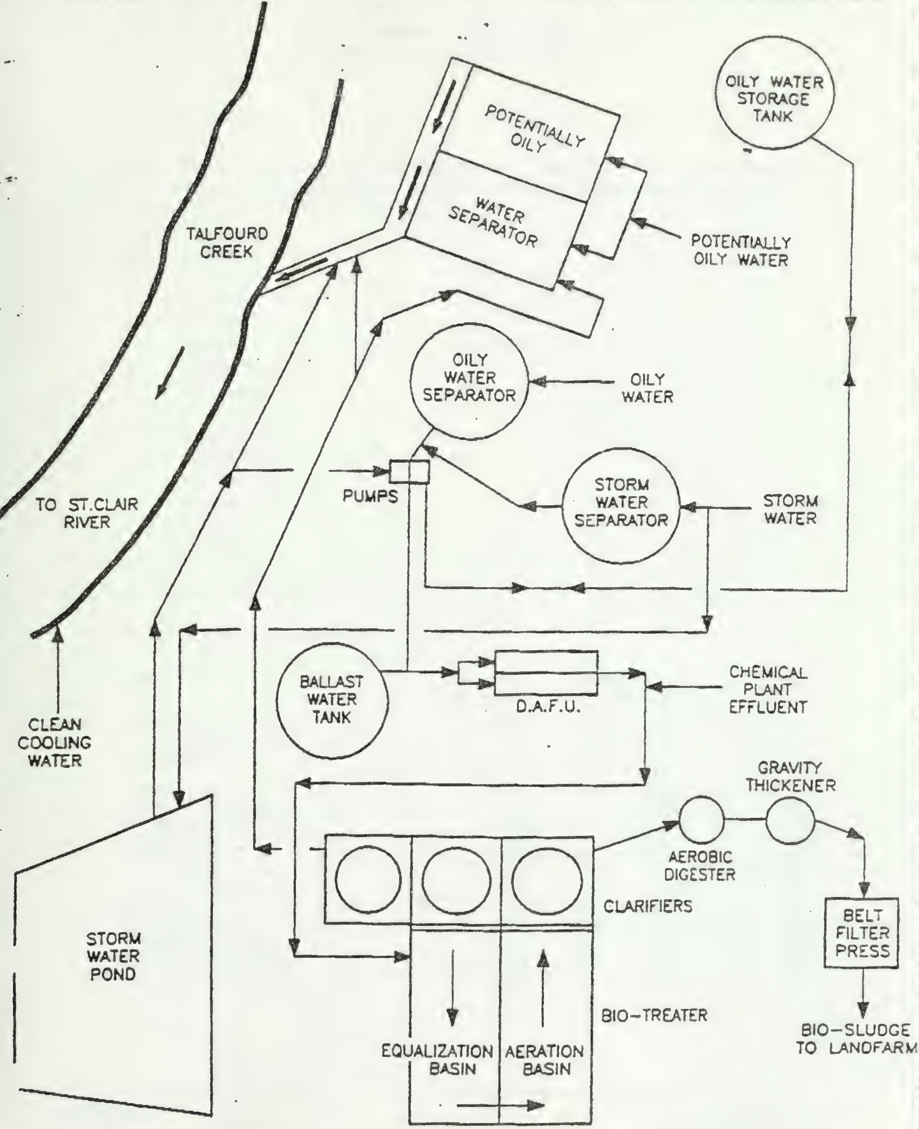
SHELL CANADA



SHELL CANADA LIMITED - CORUNNA



SHELL REFINERY EFFLUENT TREATMENT FACILITIES



8.0 CURRENT STATUS OF SUNCOR INC.'S SARNIA REFINERY

8.1 Plant Description

The Suncor Refinery is located in Sarnia on the St. Clair River. The plant went on stream in 1953 and is a conventional petroleum refinery. A number of process units have been added since the plant opened.

The saleable products are:

- benzene;
- toluene;
- xylene;
- gasolines;
- kerosene;
- jet fuel;
- stove oil;
- diesel fuel;
- furnace oil;
- bunker fuel;
- sulphur;
- asphalt.

8.1.1 Refinery Process Data

Note: All data is in M^3/day.

Process	1989 Stream Day Capacity	1989 Calendar Day Rate	Year Installed
Atmospheric Crude	14,310	11,076	#1 1953 #2 1974
Crude Desalting	14,310	11,076	#1 1953 #2 1974
Vacuum Tower	--	2,600	--
Viscosity Breaking	1,190	666	1953
Moving Bed Cat. Cracking	2,702	2,416	1953
Hydro Cracking	3,350	2,793	1984
Catalytic Reforming	4,431	3,755	1953 1974
Hydrogen Treating	4,997	4,193	1974 1984
HF Alkylation	800	679	1966
Hydrogen Plant Kg/day	100,000	100,000	1984
Total Sweeting Process	---	6,999	1953
BTX Extraction Production	2,352	2,118	1976
Sulphur Recovery Long Tons	28	24	1984

8.2 Feedstocks Processed in 1989

In 1989 there were four different Canadian crude feedstocks run. They are as follows:

Name	% Run	% Sulphur	API Gravity
Synthetic Crude	55-75	0.32	34.3
Sweet Conventional	10	0.43	38.7
Sour Conventional	10	1.15	32.0
CRW Condensate	5	0.23	55.3

The plant runs primarily on Alberta synthetic crude oil from a plant owned by Suncor.

8.3 Chemicals Used

See Appendix Section 8.15.

8.4 Water Management

8.4.1 Water Supply

Water is supplied to the refinery from the St. Clair River and about 86000 M^3/day is pumped. In addition the refinery purchases an average of 600 M^3/day from the municipality for drinking and other special uses.

8.4.2. In Plant Reuse and Recycling Techniques

The refinery uses a combination of once through cooling water and recirculated cooling water from cooling towers. Cooling water is recirculated at a rate of 185000 M^3/day and once through is used at 84000 M^3/day.

Once through cooling water is kept at a pressure greater than that of the hydrocarbon side of exchangers so that the leaks will not enter the water side and thus contaminate the once through cooling water. Chlorine is added on a shock basis for algae control at the rate if 4-5 ppm.

The recirculated water uses a phosphate based treatment program at a PO_4 concentration of 100 ppm. One set of towers operates at 4 to 5 cycles of concentration while the other set operates at 5-6 cycles. Both towers operate at a 5C° temperature differential (9F°).

Currently about 25% of the 470 M^3/day stripped sour water is not being reused in the desalter. A new sour water recovery system is being built which will reduce the amount of river water used by 350 M^3/day.

Steam condensate is collected and returned to the steam plant wherever this can be done economically.

8.4.3. Ratio of Wastewater to Feed Charge

Based on feedstock charge rate the refinery produces 812 M^3 of process wastewater for each 1000 M^3 of feed stock.

The plant produces 28.3 Canadian gallons of process wastewater for each barrel of feedstock processed. Expressed in terms used under Federal Regulation and Guidelines for Petroleum Refineries the rate is 19.7 Canadian gallons per minutes per 1000 BPD charge.

This plant can be considered a moderately low water user, however if recirculated water were used for 100% of cooling, the blow down from the tower would increase the total volume of process wastewater by 3 to 5%.

8.4.4. Cooling Methods Used

About 60% of the plant cooling requirements are met by recirculated water and cooling towers, about 35% by once through cooling water and less than 5% by air cooling. The recirculated water uses an organic phosphate treatment system.

8.5 Segregation of Sewer Systems

The sewers are segregated into four systems:

1. *Once Through Cooling Water*

   For heat exchange with once through cooling water, the water side of the exchanger is kept at a higher pressure than the hydrocarbon side to virtually eliminate the leakage problem.

2. *Sanitary Sewage*

   Sanitary sewage is collected in a separate system.

3. *Process Water*

   This sewer system contains all water which comes in contact with the process, such as wastewater from the desalter, neutralized spent caustic cooling tower blow down landfarm leachate, tank drainings, ballast water and storm water.

4. *Storm Water*

   This sewer system contains potentially contaminated storm runoff from process pads, tank farms, roads, roofs, etc. Uncontaminated storm water from undeveloped areas is ponded and may be diverted to the wastewater treatment system under controlled flow if it is not within set limits. It is also used as a source of firewater.

5. *Landfarm Leachate*

   Leachate is collected in a collection basin.

8.6 Sources of Wastewater

The total volume of process wastewater measured by the MISA program in 1989 was 8994 M^3/day averaged over the year. Most of the water comes from general process sources however a number of specific sources have been identified and are listed below because they may offer opportunities for reduction.

	Annual Average Flow M^3/day
Ballast Water	275
Cooling tower blowdowns	300
Desalter	625
Pump glands	1152
Storm and contaminated water	N/A
Boiler blowdown	5
Stripped sour water	470
Cat. Reformer Scrubber Liquid	130 M^3/yr
Landfarm leachate	N/A

8.7 Opportunities to Reduce Wastewater Flow

Although this plant already has a fairly low rate of process wastewater to feedstock the use of once through cooling water to cool the pump glands should be studied. The water enters the process water stream and contributes almost 13% to the flow. Consideration might be given to some kind of closed system.

8.8 Description of Wastewater Treatment System

8.8.1 Discussion of Schematic

Process wastewater goes to an API separator where phosphoric acid may be added to adjust the pH. Wastewater from the API separator then goes to a Vertical Tube Coalescer (VTC) oil separator and then to a compartmented equalization basin. From the basin the water is sent to a WEMCO induced air flotation unit and then to an aeration basin where polyelectrolyte may be added. The process wastewater is further aerated in second aeration basin and then the solids are settled in two clarifiers in parallel. Effluent streams from the clarifiers are combined and are sent to an impounding basin. This basin is equipped with a rope oil skimmer to remove any visible surface oil. The treated effluent wastewater is then discharged directly to the St. Clair river or recycled back through the biological treatment system if it does not meet prescribed quality.

Ballast water is pumped to a holding tank and then to the process water treatment system for full biological treatment.

Sanitary sewage is pumped from the sewage holding tanks to aeration basin #1 for treatment along with the process wastewater.

Once through cooling water is sent to an API separator before joining treated process water in the outfall to the St. Clair river.

Storm water collected from potentially contaminated areas passes through a separator for removal of most of the oil. It then enters a WEMCO induced flotation unit for further oil and suspended solids removal. Normally it would then go directly to biological treatment. If the flows are too large an equalization basin may be used to prevent shock loading to the biological unit. Clean storm water falling on undeveloped areas is impounded and also goes to the biological treatment system on a controlled basis.

Leachate is collected in a leachate collection basin and transported back to the wastewater treatment area by vacuum truck.

The caustic solution (131 M^3 in 1989) used in absorbing off gases during regeneration of the Catalytic Reformer reactors is treated for removal of dioxins by filtration through an activated carbon filter. The aqueous phase is returned to the wastewater treatment system. No dioxins have been detected in the plant effluent. There were 3 reactors regenerated in 1989.

8.8.2 Sampling and Monitoring Frequency

The process wastewater is sampled three times per week for oil and grease, suspended solids, ammonia, sulphides and total organic carbon, once a day for pH, phenols, volatile suspended solids and flow. A fish toxicity test is done once per month. The plant has a single outfall.

8.8.3 Summary of MISA Process Effluent Results for 1989

Effluent concentrations and loadings measured during the 12 month MISA monitoring program are shown below. Concentrations are an average for the 12 month period. Effluent loadings were calculated utilizing the average flow rate for the 12 month monitoring period.

Priority Pollutants Found in Process Effluent
Suncor Inc. (Sarnia)
MISA Monitoring Data Dec 88 to Nov 89

Parameter	Min	Max	Avg	Unit	Loading Kg/day	Avg Concen. 1989 mg/L	Ontario Obj. mg/L
1,2-Dichloroethane	.00	.30	.04	ug/L	.00		
Aluminum	.00	720.00	171.67	ug/L	1.54		
Ammonia plus Ammonium	.00	20.00	2.02	mg/L	18.17	2.02	10
Arsenic	3.00	8.00	4.58	ug/L	.04		
Benzene	.00	11.30	.08	ug/L	.00		
COD	8.00	27.00	20.67	mg/L	185.91	20.67	200
Chloroform	.00	3.90	.67	ug/L	.01		
Chrysene	.00	.40	.03	ug/L	.00		
Copper	.00	140.00	15.00	ug/L	.13	0.015	1
Cyanide Total	.00	.06	.02	mg/L	.18		
DOC	.00	91.00	9.06	mg/L	81.49		
Ethylbenzene	0	4.90	.06	ug/L	.00		
Hydrogen ion (pH)	6.20	8.40	7.31				
Methyl chloride	.00	5.40	.45	ug/L	.00		
Nickel	.00	10.00	1.67	ug/L	.02	0.002	1
Nitrate + Nitrate	2.03	13.90	8.90	mg/L	80.05		
Oil and Grease	.00	8.90	1.19	mg/L	10.70	1.19	10
Phenolics (4AAP)	.00	120.00	6.87	ug/L	.06	0.007	0.02
Selenium	2.00	6.00	3.25	ug/L	.03		
Sulphide	.00	.08	.02	mg/L	.18		
TOC	.00	88.00	10.11	mg/L	90.93		
Toluene	.00	15.20	.33	ug/L	.00		
Total H7CDD	.00	.04	.02	ng/L	.00		
Total Kjeldahl nitrogen	.00	.60	.24	mg/L	2.16		
Total phosphorous	.00	1.50	.20	mg/L	1.80		
Total suspended solids	2.00	130.00	7.32	mg/L	65.84	7.32	15
VSS	.00	20.00	4.61	mg/L	41.46		
Zinc	20.00	110.00	51.67	ug/L	.46	0.052	1
m-Xylene and p-Xylene	.00	4.30	.08	ug/L	.00		
o-Xylene	.00	5.90	.16	ug/L	.00		

Avg daily process flow 8,994.270 m^3/day

8.9 Comparison of Effluent with Ontario Effluent Quality Objectives (OEQO)

During the 12 month MISA monitoring program the refinery met all the OEQO on an averaged basis, however on a daily basis there were exceedences for ammonia and total suspended solids.

8.9.1 Comparison with U.S. EPA BPT/BAT Limitations

During 1989 the following number of exceedences would have occurred if the U.S. EPA BPT/BAT limitations had been applicable.

Daily maximum limits	•	Total Suspended Solids	1
30 day average limits	•	No exceedences	

8.10 Fundamental Factors Affecting Effluent Quality

The feedstocks used by this plant have a fairly high gravity and low sulphur content and this combination tends to favour easier treatment of the effluent.

The plant is highly integrated and employs processes such as Vis Breaking (a type of thermal cracking) and Catalytic Cracking both of which are known to produce numerous contaminants in the effluent.

The wastewater treatment plant is not overloaded and uses present day technology. A number of the process units were built in 1953 at a time when sewer segregation was not common. The plant has an ongoing program to reduce overall water use. A sensor installed on the influent to the API separators handling once through cooling water has proven effective in alerting the operators in case of an oil emission to the system.

The location of the plant downstream of most of the 45 industries located in the area means that the intake water contains contaminants from upstream. Of significance are measurable levels of contaminants such as phenols, benzene, toluene and ethyl benzene in the water intake.

8.11 Control Orders Issued

There are no outstanding control orders in effect.

8.12 Capital and Annual Operating Costs for Wastewater Treatment System - 1970-1989

The refinery reported spending $10,070,000 in 1989 dollars between the above years. No break down of costs is available.

One in plant study showed that operating costs are about 1.5 cents per barrel of wastewater treated. This equates to about $430,000 per year.

8.13 Best Management Practices

8.13.1 Training

All employees go through a training program which includes environmental issues. Midterm and final exams in oral and written form are part of this training program. This training program is performed on-site.

Wastewater treatment operators have a 2 week basic operating training program, then a 3 to 4 month on the job training as an apprentice. This training includes preparing the employee to be able to perform equipment maintenance, and deal with emergency wastewater treatment situations.

8.13.2 Manuals

A detailed technical process manual outlines the working principles on specific equipment as well as operating procedures.

The use of the CPPI wastewater treatment operator's manual is expected to commence in the first quarter of 1991. This will be a 40 hour, 1 week session at Lambton College. All wastewater treatment operators will be required to take this course.

8.13.3 Specifications

Targets for effluent quality have been set and the computer flags those areas that exceed the specification. Operators do some basic testing of effluent quality to determine if the water quality is within specification. Reports on these occurrences are provided to the shift manager and immediate access to the information may be achieved through the computer system.

8.13.4 Responsibility/Authority

The unit supervisor reports to the shift manager. The shift manager is responsible for calling in spills to the MOE.

Aside from operators, approximately 6 people have a part-time responsibility for water treatment. They include the:

- area manager;
- process engineer;
- process design engineer;
- shift manager;
- environmental specialist; and the
- environmental manager.

Other groups which may have a part-time responsibility for water treatment are the:

- industrial hygiene group;
- instrumentation;
- maintenance;and
- landspreading.

8.13.5 New Projects

Before a new project proceeds it must be reviewed by an internal review group which assesses the possible environmental impacts.

The area manager is responsible for the quality of wastewater leaving the plant. If anything occurs to impact the wastewater results, it is his job to solve it and assign a priority. The area manager reports to the director of operations on the discharges leaving the site.

A 3, 5, and 10 year budget has been formulated for the company as a whole. Environmental issues are an important and specific part of the budget.

8.13.6 Oil Spills in Plant

A vacuum truck is available on site, and other trucks are available on contract if required. Two spill vessels, one work boat, and one transportation vessel are available for spills reaching the St. Clair river. The manager of emergency response is responsible for all emergencies including spills on site and off site. There are internal spill cleanup teams prepared to deal with spills immediately.

In 1989 there was a total of 13 "reportable" liquid spills to the Ministry of the Environment. Of these, 6 involved spills outside the plant property. Most were very small involving a litre or so of oil. Two small spills inside the plant (less than 3 Kg) involved benzene which is a water soluble and which no boom can completely arrest.

8.13.7 Landfarming

A five acre landfarm is located on the site. Biosludge from the wastewater treatment site and sludge from separators are spread on the landfarm.

The leachate is tested each month for oil and TOC. Once per year the soil and groundwater are tested for metals.

8.14 Conclusions

The operating staff in this plant require 3 to 4 months training on the job before they are allowed to take responsibility for making decisions. This training will be augmented in 1991 when Lambton College commences a new formalized operator training program.

The plant is clean and the wastewater treatment equipment appears to be well maintained with an experienced staff in charge. A number of good management practices were uncovered during the plant visit.

The plant is a fairly low wastewater producer taking into account the age of the plant. The use of once through cooling water however tends to reduce the volume of process water because it removes heat without producing blow down.

The storm water is well segregated and the contaminated portion receives full secondary treatment.

The processes employed in the plant are those which are known to produce large quantities of contaminants in the water to be treated. In spite of this, the effluent is generally of a high quality.

A large number of liquid spills were reported in 1989, however they were not of major significance and were easily cleaned up. The Ministry of the Environment sets no minimum size for a "reportable" spill. As a result there could be a wide discrepancy between plants as to what requires reporting and what does not.

8.15 APPENDIX

- chemical used
- process flow schematic
- waste water schematic

CHEMICALS USED

Gas Plant, Alkylation Plant, Wastewater Treatment -
ALCHEM 5W25
AMMONIA
CAUSTIC POTASH - FLAKE
CAUSTIC SODA SOLUTION
HYDROFLUORIC ACID-ANHYDROUS
HYDROGEN PEROXIDE
HYDROGEN PEROXIDE (3%)
HYDROGEN PEROXIDE (50%)
METHANOL
PHOSPHORIC ACID
SODA ASH/SODA CONCENTRATE
SODIUM BICARBONATE
SULPHURIC ACID

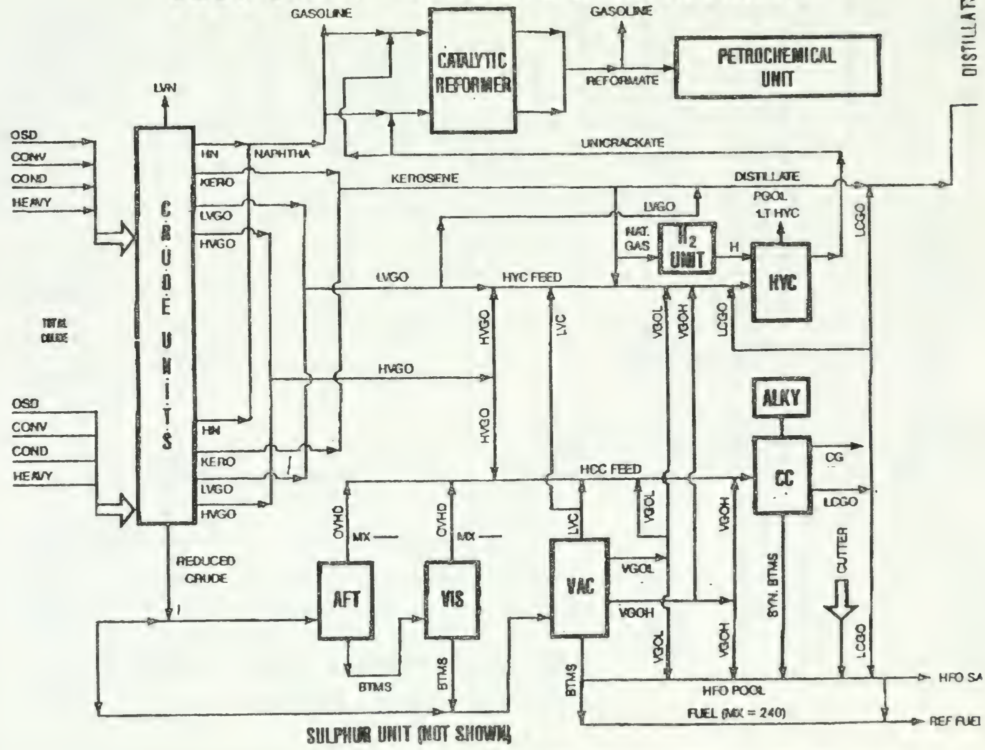
TANK FARM, CB#1 -
CHLORINE

PLANT #1, CB#2 -
ALCHEM 5196
ALKAMEEN 96
AMMONIA
CAUSTIC SODA SOLUTION
CAUSTIC SODA - FLAKE
CHEMTROL 840 (Sodium Hypochlorite 12.5%)
DEARBORN 517
DEARBORN 606
DEARBORN 66
DEARBORN 698
DEARBORN 817
HYDROCHLORIC ACID (50%)
METHANOL
SODIUM HYDROXIDE
SULPHURIC ACID

PLANT #2, CB#3 -
ALCHEM 169
ALCHEM 5E41
ALKAMEEN 96
CHLORINE
CL-2490
CL-361
DB-100 ANTIFOAM
H-450 MICROBICIDE
METHANOL
PHREEGUARD
SULPHURIC ACID
SUPER FILMEEN 20

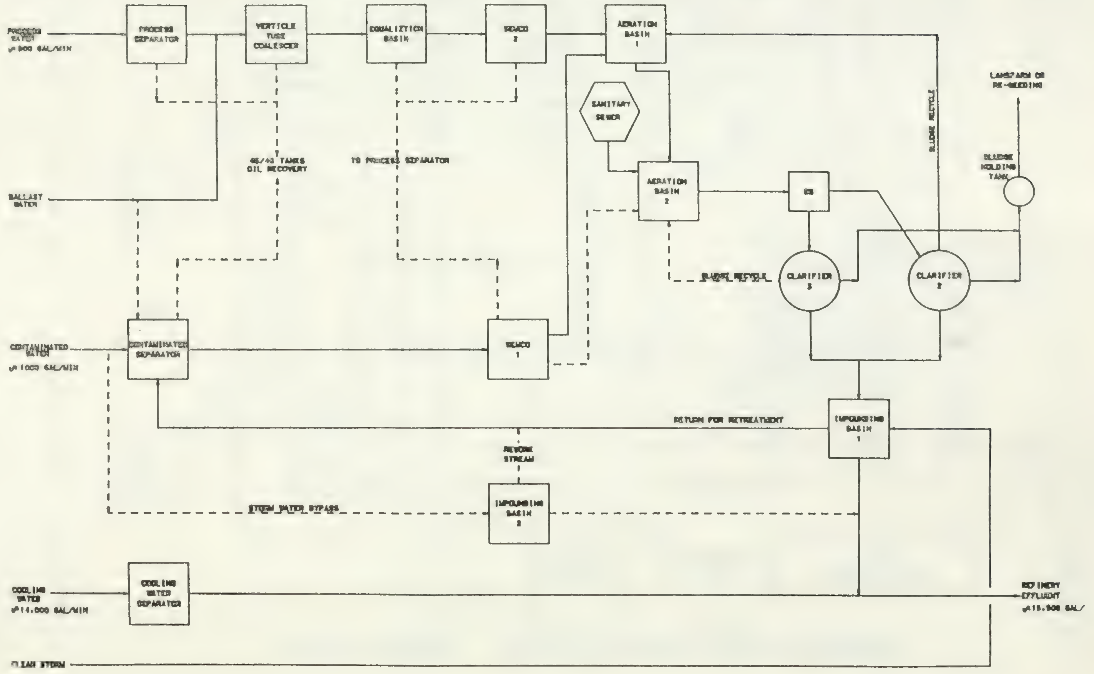
PLANT #3, CB#4 - ALKAMEEN
AMMONIA
CL-361
CL-37 DEFOAMER
CL-5 CORROSION INHIBITOR
DEARBORN 66
DEARBORN 687
DEARBORN 817
HYDROCHLORIC ACID (50%)
H-450 MICROBICIDE
METHANOL
PETROMEEN FC-629
PETROMEEN WS-58
PHREEGUARD 2205
SODA ASH/SODA CONCENTRATE
SULPHURIC ACID

FLOW CHART – SUNCOR SARNIA REFINERY



SUNOCO SARNIA REFINERY

WASTE WATER TREATMENT FACILITY – 1990



9.0 CURRENT STATUS OF ESSO PETROLEUM'S NANTICOKE REFINERY

9.1 Plant Description

The Nanticoke Refinery is the newest of Ontario's petroleum refineries, going on stream in 1978. Modifications were made in 1987 to improve energy efficiency and increase clean product recovery. The refinery was purchased by Esso in 1989. Currently, Esso employs about 450 people, including about 140 contract employees.

The Nanticoke Refinery is located two miles from the north shore of Lake Erie and 35 miles southwest of Hamilton. The site comprises 1472 acres (596 hectares). About 450 acres are developed.

Refinery products and by-products include:

- Liquified Petroleum Gas
    - propane
    - propylene mixtures
    - butane mixtures
- Gasolines
- Jet Fuel
- Diesel Fuel
- Stove Oil
- Furnace Fuel Oil
- Heavy Fuel Oil
- Sulphur

9.1.1 Refinery Process Data

Note: All data is in M^3/day.

Process 1989 Stream	1989 Calendar Day Capacity	Year Day Capacity	Installed
Crude Unit	16676	18360	1978
Crude Desalting	16676	18360	1978
Vacuum Stilling Unit	5051	5500	1978
Fluid Cat. Cracking	6353	6623	1978
Catalytic Reforming	4129	3955	1978
Hydrogen Treating	4129	3955	1978
Sulphuric Acid Alkylation	1271	1001	1983
Total Sweeting Process Merox (6 units)	11251	4225	
Sulphur Recovery LTD	35	17	1979

9.2 Feedstocks Run in 1989

The following crude streams were run in 1989.

Name	% Run	% Sulphur	API Gravity
Sweet Lube Blend	52	0.35	39.4
Sweet SW	30	0.45	38.4
Light Sour Blend	9	1.15	33.0
Syncrude	4	0.30	34.6
U.S. Domestic	4	--	40.6
Miscellaneous	1	--	--
Total	100		

9.3 Chemicals Used

See appendix, Section 9.15.

9.4 Water Management

9.4.1 Water Supply

The Refinery purchases about 6000 M^3/day (1100 gpm US) of Lake Erie water from the Ministry of Environment as make-up water for process and cooling uses. The Ministry chlorinates the incoming water supply. The approximate distribution and treatment of incoming water is presented below. This information was obtained during the site visit:

Potable Water (50 gpm) - filtration, disinfection with sodium hypochlorite.

Boiler Feed Water (500 - 700 gpm) - filtration, demineralization.

Cooling Tower Make-up (300 - 350 gpm) -filtration, addition of antifoaming agents.

Service Water (200 gpm) - no treatment by Esso.

9.4.2 In-Plant Water Reuse and Recycling Techniques

To minimize water usage, the Nanticoke Refinery was constructed with air fan coolers for about 85 % of the process thermal loading, and with recirculating cooling water systems for the balance. There is no once through non-contact cooling water used at the refinery. Based upon the reported cooling tower make-up water rate from the questionnaire, the refinery uses less than 2 gallons of cooling water per barrel of feedstock.

The refinery was designed to minimize the amount of process wastewaters, contaminated surface water runoff and miscellaneous wastewaters requiring treatment. Steam condensates in excess of 10 gpm are collected and returned to the Boiler Feed Water Plant. Vacuum distillation tower condensates are recycled to the crude oil electrostatic desalters. Sour condensates from the FCCU and crude unit are stripped for removal of hydrogen sulphide and ammonia-N. About 150 gpm of the stripped sour water is reused as desalter make-up. FCCU regenerator waste flue gas containing carbon dioxide is used to neutralize sulphitic, phenolic and alkylation spent caustic solutions in a vertical contacting tower, thus eliminating the need for mineral acids for neutralization. Pump seal glands are operated with recirculating cooling water, thus saving about 10 gpm per pump. The refinery was constructed with several separate sewer systems and storm water collection systems. Storm water from only the immediate process areas are processed in the end-of-pipe wastewater treatment facilities.

The refinery experimented with reuse of treated wastewater effluent for pad wash water, process water make-up and to add pressure in the fire protection system. However, high dissolved solids levels were cited as causing corrosion problems in certain applications. Treated effluent is currently not recycled or reused.

9.4.3 Ratio of Wastewater to Feed Charge

Based upon the charge rate to the crude unit and the six month average wastewater flow reported to MISA for the period June -November 1989 (1204 gpm; 6565 M^3/day), the Nanticoke Refinery produces the following amounts of total wastewater effluent:

357 M3/1000 M3 of feedstock
12.5 Canadian gallons per barrel of feedstock
8.7 Canadian gpm/1000 barrels per day of feedstock
15.0 U.S. gallons per barrel of feedstock

9.4.4 Cooling Methods Used

As noted above, the Nanticoke Refinery uses air cooling to dissipate 85 % of the refinery thermal loading, the highest of all Ontario refineries. Recirculated evaporative cooling water systems are used for the balance of the cooling applications,(30,000 gpm recirculating rate; 4.8 - 5.0 cycles of concentration).

9.5 Segregation of Sewer Systems

The refinery was constructed as a new source with maximum sewer segregation. There are four main sewer systems and four subcollection systems. Wastewater streams that have been segregated include process wastewaters, ballast water, clean storm waters, sanitary wastewaters, high dissolved solids streams, oily wastewaters, sour waters and spent caustics. Following is a list of the major sewers:

Contaminated Water Sewer
- all process wastewaters that come into direct contact with hydrocarbons.
- sour water stripper effluent
- spent caustic neutralizer effluent
- storm and pad wash waters that have the potential to become contaminated
- miscellaneous wastewaters

Clean Storm Water Sewer
- storm water from the 450 acres of developed area, excluding stormwater from immediate process areas.

Sanitary Sewer

High Dissolved Solids Sewer
- neutralized demineralizer regeneration wastewaters
- boiler blowdowns

Oil Sewer
- oil drainings and leaks from pumps and other process equipment.

Sour Water Sewers (2 above ground)
- FCCU sour water system
- desalter sour water system

Spent Caustic Collection System
- sulphitic spent caustic
- phenolic spent caustic
- alkylation spent caustic

Ballast Water System
- collection system and oil separation tank

9.6 Sources of Wastewater

Following is a summary of wastewater sources obtained from the completed questionnaire prepared by Esso. Note that the sum of the reported annual average wastewater flows exceeds the annual average volume of make-up water purchased from the Ministry by nearly 20 %. The water imbalance is a result of including an estimated storm water flow, the rough methods of estimation used for most sources and possible double counting of certain itemized flows in the refinery process wastewater flows. In addition to the flows listed below, landfarm leachate is also collected and routed to the wastewater treatment system.

The refinery employs continuous regeneration of the Catalytic Reformer catalyst and therefore does not have water or caustic scrubbers for catalytic reformer regeneration off gases. Thus, there is no direct contribution of chlorinated dibenzo-p-dioxins (CDDs) and chlorinated dibenzoforans (CDFs) to the wastewater effluent from catalytic reformer operations.

Source	Annual Average Flow M^3/day
Refinery process wastewater	4364
Ballast water from ships	174
Storm water treated in main treatment facility (estimated)	134
Water treatment blowdown	240
Boiler blowdown	60
Cooling tower blowdown	545
Sanitary	82
Desalter	1086
Sour Water Stripper	584

9.7 Opportunities to Reduce Wastewater Flow

In view of the extremely low ratio of wastewater to feedstock there does not appear to be any obvious suggestions for reducing wastewater. The only possibility is the reuse of storm water following filtration to remove suspended solids.

9.8 Description of Wastewater Treatment System

9.8.1 Discussion of Schematic

The Nanticoke Refinery provides pretreatment for the following process and miscellaneous wastewater streams:

Stream	Pretreatment
Vacuum tower condensates	To desalter
Desalter sour water	Cooled & then to wastewater treatment plant
FCCU sour condensates and Crude Unit	Sour water stripper
Spent caustic solutions	Neutralization with FCCU regenerator flue gas
Strong acid - alkylation	Regeneration off-site
Weak acid	Neutralization
Ballast water	Oil/water separation
Equipment cleanouts	Slop tank/Oil separation
Oily wastes and spills	Slop tank/Oil separation

The effluents from each of the pretreatment systems are combined with other refinery process wastewaters, minimal blowdowns from the non-contact cooling water systems, stormwater from process areas, and sanitary wastewaters and treated in the end-of-pipe treatment system illustrated in Figure 1. The major treatment units include primary oil separation in API-type separators; equalization; intermediate oil separation and chemical addition; biological treatment; secondary clarification; mixed-media filtration; and, polishing in final holding ponds. Sanitary wastewaters are added at the influent to biological treatment and "clean" high dissolved solids streams are added to the influent of the final polishing ponds. The refinery has the capability to divert untreated or partially treated wastewaters and excess stormwaters to lagoons at the treatment facility for eventual reprocessing. The final effluent is piped to Lake Erie and discharged through a diffuser.

Waste biological and oily sludges are landfarmed in a field located adjacent to the wastewater treatment facility. Surface leachate from the landfarm is collected, tested and returned to the wastewater treatment facility if necessary. Sub surface leachate is collected through a drain tile system and is similarly treated.

Storm water from the developed area of the site, excluding that from immediate process areas which is collected and treated, is routed to 2 storm water holding ponds (6 million U.S. gallons) equipped with an oil separation system. The stormwater is tested prior to release to a small creek that empties into Lake Erie. Storm water from the undeveloped areas of the site is segregated from other storm waters and process wastewaters and allowed to run off through natural and man-made drainage systems.

9.8.2 Sampling and Monitoring Frequency

Routine wastewater effluent sampling is summarized below:

Parameter	Grab Sampling	Composite Sampling
Oil and Grease		3/Week
Suspended Solids		Daily
Ammonia-N	4/Day	3/Week
pH	4/Day	Daily
Phenolics	4/Day	Daily
Sulphides	4/Day	Daily
Turbidity	4/Day	
Phosphates	4/Day	3/Week
Flow	Continuous	Totalizer
Fish Toxicity	Monthly	

The suspended solids determinations include measurements of Total Suspended Solids and Volatile Suspended Solids. Analyses of grab samples obtained for operational purposes are not conducted using MISA analytical protocols.

9.8.3 Summary of MISA Monitoring Results - 1989

The MISA monitoring results for the period December 1988 - November 1989 are summarized in the table on the following page. A number of priority pollutants were found at very low concentrations in spite of the excellent treatment system used.

Priority Pollutants Found in Process Effluent
Esso Petroleum Canada (Nanticoke)
MISA Monitoring Data Dec 88 to Nov 89

Parameter	Min	Max	Avg	Unit	Loading Kg/day	Avg Concen. 1989 mg/L	Ontario Obj. mg/L
1,1-Dichloroethane	.00	.37	.08	ug/L	.00		
1,1-Dichloroethylene	.00	1.56	.31	ug/L	.00		
2-Methylnaphthalene	.00	.10	.01	ug/L	.00		
Aluminum	20.00	240.00	133.33	ug/L	.87		
Ammonia plus Ammonium	.00	8.79	.35	mg/L	2.29	0.35	10
Arsenic	5.00	17.00	11.25	ug/L	.07		
Benzene	.00	2.10	.08	ug/L	.00		
Bis(2-ethylhexyl) phthalate	.00	11.00	3.67	ug/L	.02		
Bromoethane	.00	.95	.16	ug/L	.00		
COD	11.00	57.00	30.58	mg/L	200.25	30.58	200
Cadmium	.00	.60	.14	ug/L	.00		
Chloroform	.00	5.60	1.25	ug/L	.01		
Chloromethane	.00	7.42	2.09	ug/L	.01		
Chromium	.00	10.00	1.58	ug/L	.01	0.002	1
Chromium (hexavalent)	.00	31.00	12.00	ug/L	.08		
Copper	.00	10.00	2.92	ug/L	.02	0.003	1
Cyanide Total	.00	.02	.01	mg/L	.07		
DOC	2.10	35.00	7.26	mg/L	47.54		
Di-n-butyl phthalate	.00	2.20	.73	ug/L	.00		
Hydrogen ion (pH)	6.50	8.60	7.76				
Lead	.00	4.00	.43	ug/L	.00	0.00043	1
Mercury	.00	.15	.06	ug/L	.00		
Methylene chloride	.00	33.00	5.71	ug/L	.04		
Molybdenum	.00	40.00	33.33	ug/L	.22		
Nickel	.00	8.00	1.17	ug/L	.01	0.001	1
Nitrate + Nitrite	.87	4.41	2.21	mg/L	14.47		
Oil and grease	.00	6.50	1.58	mg/L	10.35	1.58	10
Phenol	.00	.10	.02	ug/L	.00		
Phenolics (4AAP)	.00	20.00	3.87	ug/L	.03	0.004	0.02
Selenium	3.00	8.00	5.50	ug/L	.04		
Sulphide	.00	.30	.03	mg/L	.20		
TOC	4.80	11.30	6.87	mg/L	44.99		
Thallium	.00	20.00	12.67	ug/L	.08		
Toluene	.00	1.29	.04	ug/L	.00		
Total Kjeldahl nitrogen	.94	1.63	1.22	mg/L	7.99		
Total phosphorous	.00	1.30	.28	mg/L	1.83		
Total suspended solids	.00	19.00	6.91	mg/L	45.25	6.91	15
VSS	.00	12.80	4.31	mg/L	28.22		
Vanadium	.00	9.00	1.83	ug/L	.01		
Zinc	14.00	40.00	27.00	ug/L	.18	0.027	1
m-Xylene and p-Xylene	.00	1.68	.03	ug/L	.00		
o-Xylene	.00	1.52	.03	ug/L	.00		

Avg daily process flow 6,548.501 m^3/day

9.9 Comparison of Process Effluent Quality with Ontario Objectives

As shown in the table on the following page, the Nanticoke Refinery operated well within the Ontario Effluent Quality Objectives on an annual average basis. Except for Total Suspended Solids (TSS), all individual effluent concentrations determined during the monitoring period were at or below the Ontario objectives. The maximum TSS concentration recorded was 19 mg/L vs. the Ontario objective of 15 mg/L.

9.9.1 Comparison with U.S. EPA BPT/BAT Limitations

During 1989 this refinery would have met all of the flow and loading requirements specified under the U.S. EPA BPT/BAT regulations. No exceedences of any kind would have occurred.

9.10 Fundamental Factors Affecting Effluent Quality

The Nanticoke Refinery was constructed as a new source refinery with state-of-the-art engineering for wastewater minimization, wastewater pretreatment, end-of-pipe wastewater treatment, non-contact cooling water minimization, and storm water management. Accordingly, the discharge of total effluent is the lowest of the Ontario refineries in terms of volume per unit of throughput and in terms of mass discharge of most, if not all, pollutants under consideration for the limits regulation.

9.11 Control Orders Issued

None outstanding.

9.12 Capital and Annual Operating Costs for Wastewater Treatment Facilities

Capital costs for wastewater treatment facilities, including pretreatment facilities and some separate sewer costs, were reported to be about 30 million dollars (1977 - 1978). The investment cost for the end-of-pipe wastewater treatment facilities were reported to be 15 - 17 million dollars (1977 - 1978). This represents a capital investment of $91 million in 1989 dollars.

Annual operating costs for all wastewater treatment facilities, including pretreatment facilities, are reported to be about 1.5 - 2.0 million dollars (current), and for the end-of-pipe wastewater treatment facilities, about 0.75 million dollars (current). Total is $2.5 million per year.

9.13 Best Management Practices

9.13.1 Training

New operators receive three to six weeks of orientation training, followed by three to six months of on-the-job-training with experienced operators and supervisors. Environmental awareness and controls are worked into the orientation and training. The refinery also has a "pay for knowledge" system where operators are rotated among different jobs with advancement tied to knowledge and ability. Salaried employees receive environmental orientation training.

9.13.2 Manuals

The refinery has detailed work practice manuals for each position. Environmental controls and work practices are integrated into the job requirements. The refinery has a comprehensive manual for each wastewater treatment operator that details treatment facility operations.

9.13.3 Specifications

Wastewater treatment operators do not have written quality specifications for the effluent from each treatment module. Operations of the wastewater treatment facilities are keyed to variations in untreated wastewater quality.

9.13.4 Responsibility/Authority

The refinery has established clear lines of authority and responsibility regarding all aspects of environmental control, including operation of wastewater treatment facilities, spill response and environmental objectives.

9.13.5 New Projects

Environmental programs staff become involved in new projects at the earliest possible time and attempt to deal with new environmental issues in an anticipatory mode. The refinery has no current plans to upgrade the wastewater treatment facilities.

Wastewater treatment operators are beginning to implement a statistical process control type system to aid in responding to variations in incoming wastewater quality.

9.13.6 Oil Recovery and Oil Spills

The Refinery recovers about 100 barrels of oil per day from all sources through the slop tank and ballast oil/water separation tank. About 10 barrels per day are recovered from the oil/water separator at the wastewater treatment facility.

The refinery has an oil spill contingency plan and five spill response and vacuum trucks, one a four wheel drive vehicle. Ministry records show that a gasoline and bunker spill occurred at the loading docks in 1989. Both spills were less than 50 litres and were inside the plant.

9.14 Conclusion

The Nanticoke Refinery is clearly the exemplary refinery in Ontario with respect to wastewater minimization, wastewater pretreatment, end-of-pipe wastewater treatment, non-contact cooling water minimization and storm water management.

9.15 APPENDIX

- chemical used
- process flow schematic
- waste water schematic

CHEMICALS USED

		lb per day
Crude Desalting Atmospheric Distillation & Vacuum Distillation	CAUSTIC SODA 50%	3 700 lb
	ALCHEM 169 (heavy aromatic, napthenic acid, isobutyl alcohol Deithylene triamine	40 kg
	ALCHEM 5E91 (fatty acid esters in alkyl aromatic)	
	ACETIC ACID	0.027 USG
	DIETHANOLAMINE (2,2-imino bisethanol)	200 lb*
	AMMONIUM HYDROXIDE	50 lb
	ARI-120 (FB) (cobalt phthalocyanine, sulphonate)	0.068 USG
	ARI-100 (WS) (cobalt, phthalocyanine, sulphonate)	0.29 USG
Fluid Catalytic Cracker	COMBUSTION PROMOTERS (platinum, salt, alumina)	8 lb
	FCCU CATALYST (ammonium oxide, sodium oxide, aluminum oxide, silicon oxide)	5 tons
	ARI-100 (FB)	0.068 USG
	ARI-100 (WS)	0.29
	CAUSTIC SODA 50%	1850 lbs
	PET-1202	5 USG
	PET-1320 (alkylpolyamines in water and isopropanol)	50 USG
	ACETIC ACID	0.027
	DIETHANOLAMINE	200 lb
	ETHYL HITEC 4740 (di-sec-butyl -p-phenylene amine, 2,6 di-tect-butylphenol, ortho-tect-butylphenol	250 lbs
Catalytic Reforming Unit	UNIFIER CATALYST (alumina)	9.32 lbs
	EXACT-S (thiobismethane)	0.46 USG
	111-TRICHLORETHANE (methyl chloroform)	60 lbs
	UOP-SAB2 (alumina)	2700 lb*
	UOP-R32 (platinum, aluminum support)	150000 lb*
	KAISER A203 (alumina)	54.8 lbs
	ALCHEM 5196 (3-methoxy-propylamine)	2 USG
	ISOPROPYL ALCOHOL (iso-propanol)	9 lbs
	TRETOLITE 603 (aromatic hydrocarbon, isopropanol)	
	BETZ CORR-SHIELD K-7 (sodium nitrate)	5.48 lbs
Alkylation Unit	SULPHURIC ACID (98%)	7200 USG
	CAUSTIC SODA (15 Be) (sodium hydroxide, sodium oxide, sodium carbonate, sodium chloride, water)	2142.9 USG
	DIETHANOLAMINE	200 lb*
	ETHYL MERCAPTAN	

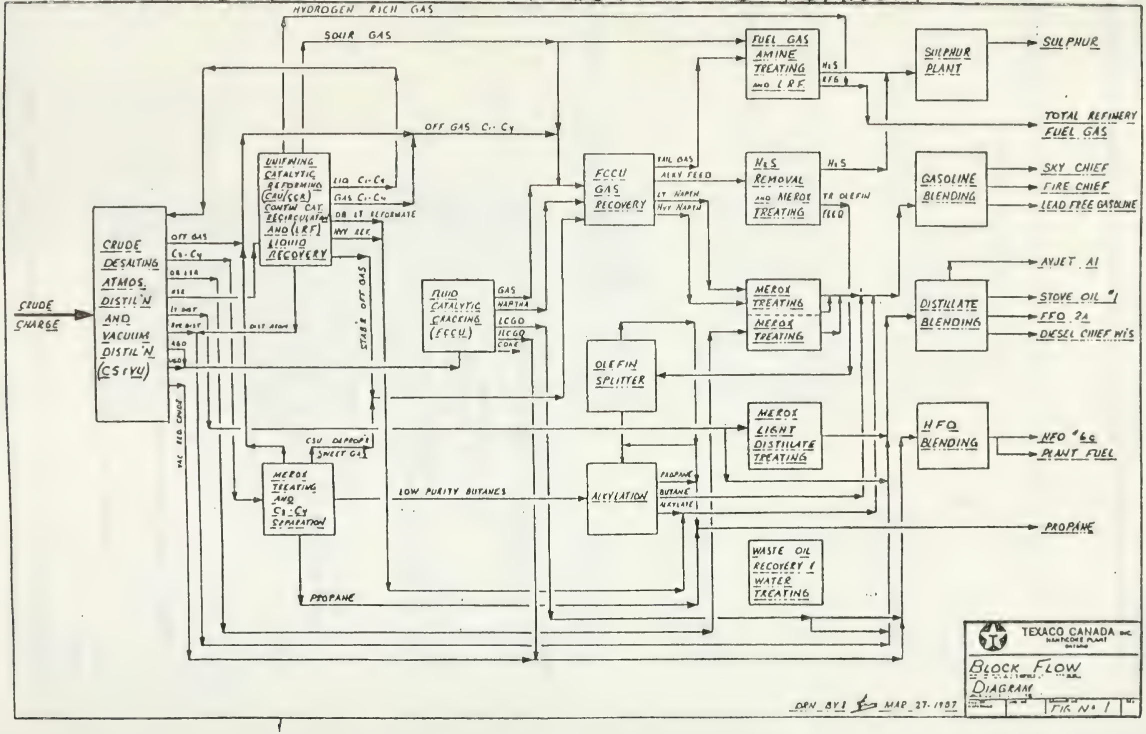
* signifies that the amount is not on a daily basis but is either a closed system or catalyst charge.

		lb per day
Boiler House	SULPHURIC ACID	200 USG
	CAUSTIC SODA 50%	1000 USG
	BETZ KI-2 (chelant acid), organo phosphate)	0.27 kg
	BETZ 1100	17 lbs
	BETZ 1190 (poly quatenary ammonium salt)	0.33 lbs
	BETZ FERROSPERSE (morpholine)	40 lbs
	BETZ CORROGEN	25 lbs
	BETZ SODIUM SULPHITE (sodium sulphite)	60 lbs
	FERRIC SULPHATE	240 lbs
	BETZ PHOS IV	2 lbs
	BETZ PHOS 4V	5 lbs
	HYDRATED LIME (calcium hydroxide)	1700 lbs
Demineralizer Resins	AMBERLITE IRA	
	AMBERLITE 200	550 ft*
	AMBERLITE 141 402	
Sulphur Recovery Unit Liquid Recovery Facilities	GENETRON 22 (chlorod, fluoromethane)	35000 lbs*
	UNION CARBIDE 3A MOLECULAR SIEVE (potassium sodium alumino silicate)	32400 lbs*
	ETHYLENE GLYCOL 99%	2000 lbs*
Catalytic Reforming Unit Liquid Recovery Facilities	UNION CARBIDE 4ADG MOLECULAR SIEVE (sodium aluminosilicate)	72000 lbs
Wastewater Treatment	PETROLITE SPC-8140 (poly quaternay 60%)	1 USG
	PETROLITE SPC-2420 (fatty amine-aliphatic quaternay in methanol and water)	0.25 USG
	SULPHURIC ACID 95%	120 lbs
	CAUSTIC SODA (25 Be)	800 lbs
Cooling Water System	BETZ 4207	0.4 lbs
	BETZ 49919 (organic Chelant)	82 lbs
	BETZ 29913 (potassium hydroxide)	103 lbs
	SLIMCIDE C30 (poly alkylene glycol, alkylene glycol methylene bisthiocynate, bisulphuric, alkylphenoxy polyalkoxy alcohol, aliphatic alcohol)	1.67 lbs
	SLIMCIDE J12 (alkyl dimethyl 8 lbs benzyl ammonium chloride)	8 lbs
	SODIUM HYPOCHLORITE (11% chlorine)	150 l
	SULPHURIC ACID	140 l
Sulphur Recovery Unit	BETZ PETROMEEN 149 (organo phosphonate polycarboxylic acid silicate salt, sodium hydroxide)	1.5 lb
	DOW CORNING (antifoam emulsion)	1.5 lb
	DIETHANOLAMINE	200 lb
	SRU CATALYST	950 ft^3/3 yrs*
	UNION CARBIDE 3A MOLECULAR SIEVE (potassium sodium alumino silicate)	32400 lbs*

* signifies that the amount is not on a daily basis but is either a closed system or catalyst charge.

			lb per day
RP & S	-	DUPONT DMD-2 (N,N-dis-alicylidene, 1,2-propane diamine)	17 l
		ASA-3	10 l
		STADIS 450 (toluene, isopropyl alcohol, mixed aromatic, solvents complex, organic acid)	100 l
		TOLAD T-39	10 l
		ETHYL HITEC 4510	10 l
		TEXACO PC-270	1100 l
		ETHYL HITEC 4778 (phenol, toluene,2,6-di-tertbutylphenol ortho-tert-butyl-phenol)	110 lbs
		BRONZE DYE (2,4-bis (dimethyl phenylazo)-resorcinol 2-{(p-dodecylphenyl)azo}-4-{(2,4-dimethylphenyl)azo} resorcinol, 2,4-bis (p-dodecyl phenylazo)-resorcinol, 2-napthelenol (phenyl azo)-azo alkyl)	5 l
		GREEN DYE (xylene, phenol, 2,2-dimethyl {1,1-biphenyl}-(4,4-diyl) bis(azo)[bis{4-nonyl}?] nonyl-1-hydroxy benzene, 1,4-dialkylamino anthraquinone	15 l
		FO-14 (isopropyl alcohol, kerosene, xylene, N,N-di salicylidene-1,2-propane diamine, 3 trade secret components)	100 l
		MMT (methylcyclpentadiene, manganese tricerbonyl, stoddard solvent, aromatic petroleum distillate)	800 lbs
Maintenance Chemicals	-	TROJAN TRL22	
		TROJAN TRL 445 HD	
		SOLVEX 3139	

ESSO PETROLEUM - NANTICOKE REFINERY



DRN BY: MAR 27. 1987

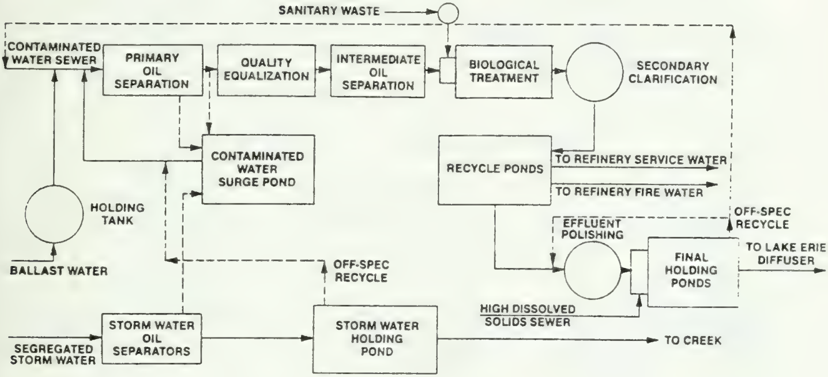
TEXACO CANADA INC.
NANTICOKE PLANT
ONTARIO

BLOCK FLOW DIAGRAM

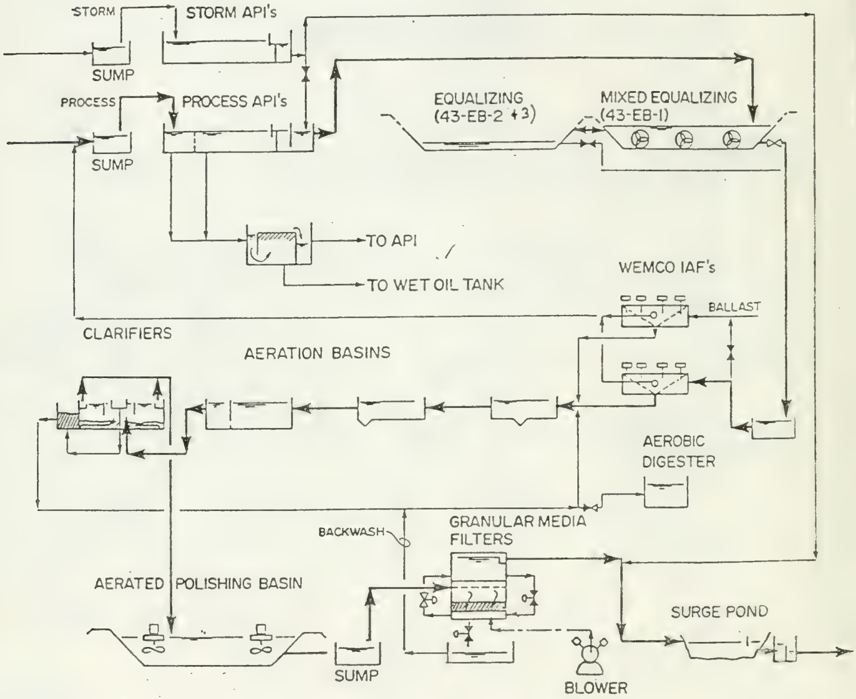
FIG No 1

ESSO PETROLEUM, NANTICOKE REFINERY

SIMPLIFIED FLOW DIAGRAM FOR WASTEWATER TREATMENT



LORO Wastewater Treatment Plant



10.0 CURRENT STATUS OF PETRO-CANADA'S OAKVILLE REFINERY

10.1 Plant Description

The Oakville plant located at the west end of Oakville, Ontario was built in 1958 and later purchased by Petro-Canada in 1983. The developed plant area covers about 260 acres of a 297 acre site. The refinery can be considered conventional producing a full slate of petroleum products. Semi finished blending stocks are imported from the Mississauga plant.

The saleable products of the plant are:

- gasoline;
- diesel fuel;
- aviation fuel;
- liquid petroleum gases
- propane and propylene
- butane and butylene
- distillate heating oils;
- residual fuel oils;
- asphalt; and
- sulphur.

10.1.1 Refinery Process Data

Note: All data is in M^3/day.

Process Unit	**1989 Stream Day Capacity**		**1989 Calendar Day Capacity**	**Year Installed**
Crude Units (2)	12600		10605	1957, 1972
Crude Desalting (2)	12600		10605	1964, 1972
Vacuum Distillation Tower	6400		4542	1957, 1972
Fluid Cat. Cracking (2)	3700		4542	1957, 1972
Catalytic Reformer	1749-2321	*	1912	1972
Hydrogen Treating	370-1020	**	1100	1960
Sulphuric Acid Alkylation	680		540	1965
Total Sweeting Process (2)	3283		2395	1968, 1972

* Dependent on feed type
** Dependent on octane

10.2 Feedstocks Run in 1989

In 1989 there were eight different crude feedstocks run. The feedstocks were as follows:

Name	% Run	% Sulphur	API Gravity
Lube Crude	11.4	0.36	38.6
Mixed Sweet	52.8	0.45	38.5
Brent	0.4	0.38-0.48	38.5
Alberta Condensate	0.4	0.32-0.45	54.0
UHG, UHC, UHL	14.7	0.45-0.60	38.3
Lloyd Blend/Cold Lake	0.7	2.6-3.0	24.8
Bow River	17.7	2.1-2.3	26.4
Bonny Light	1.9	0.15-0.25	33.0

The majority of the crude (83%) comes from Western Canada. The remaining comes from the U.S. (14.7%), Nigeria (1.9%), and the North Sea (0.4%).

10.3 Chemicals Used

See appendix Section 10.15.

10.4 Water Management

10.4.1 Water Supply

Intake water for the plant is drawn from Lake Ontario. The average annual flow rate is 9,000 M^3/day.

10.4.2 In Plant Reuse and Recycling Techniques

Water is circulated in the cooling tower system at a rate of approximately 120,000 m^3/day with 5 cycles of concentration. In 1989 the water was treated with zinc chromate inhibitors; however, in 1990 the chemical treatment program was changed to an all organic program (phosphonate). Biocides are used year-round.

Sulphidic spent caustic is reused and injected into the crude unit for crude column corrosion prevention at a rate of approximately 5.93 M^3/day. In addition, both sulphidic and phenolic spent caustic are sent to other firms (pulp and paper industries) for reuse. Excess is sent to Tricil. About 45% of the water needs of the desalter are met by stripped sour water.

10.4.3 Ratio of Wastewater to Feed Charge

Based on the charge rate to the Crude Unit, the refinery produced 462 M^3 of process wastewater for each 1000 M^3 of feedstock or 16.2 Can. gallons of wastewater per barrel of crude. In terms of Federal Regulations and

Guidelines the rate is 11.2 Canadian GPM per 1000 BPD of feedstock to the Crude Unit.

10.4.4 Cooling Methods Used

Cooling for the Trafalgar Refinery is provided by air cooling (50%) and by cooling towers (50%).

10.5 Segregation of Sewer Systems

1. *Process wastewater*

   This sewer handles stripped sour water, desalter brine process water from the north Marketing terminal, tank drainings, process waters, storm water from the process pads, ballast water, and slop tank drainings.

2. *Storm water*

   Storm water is collected in a pond from developed areas where contamination can occur.

3. *Ballast water*

   About 10% of the refinery production is shipped by water. The ballast water is collected separately in a tank.

4. *Sour water*

   This closed sewer collects sour water form the Crude Unit, Fluid Catalytic Cracking Units, flare knock out drum, and other processing units.

5. *Sanitary water*

   Sanitary waste is collected in individual holding tanks. The overflow from these tanks goes to the process sewer. One source (the Refinery Club house) has its own tiled septic bed for disposal.

10.6 Sources of Wastewater

The total volume of process wastewater as measured by the MISA program in 1989 averaged 4844 M^3/day. A number of specific sources of wastewater have been singled out.

	M^3/day	Source
Ballast water	35	To process wastewater
Storm water (contaminated) (estimated)	250	To process wastewater
Water treatment blow down	240	
Boiler blow down	350	
Cooling tower blow down	460	Directly to final effluent
Desalter effluent	530	
Sour water stripper	637	To process wastewater
Spent caustic (sulphidic)	3	To process wastewater
Spent caustic (phenolic)	0.5	Sold to Tricil
Cat. Reformer scrubber water	161 M^3/yr	To process wastewater
Pump glands	200	To process wastewater

10.7 Opportunities to Reduce Wastewater Flow

In view of the very low ratio of process wastewater to feedstock there would appear to be no obvious areas where wastewater might be reduced.

10.8 Description of Wastewater Treatment System

10.8.1 Discussion of Schematic

During 1989 the wastewater treatment system was significantly upgraded. A discussion of the treatment of the system follows.

Storm water is collected from the developed ares in a holding pond from which it overflows into the final surge pond (treated effluent lagoon). Some of the storm water is treated however the biotreater is usually fully loaded and cannot accept the storm water so that it is discharged as untreated most of the time. Run off from the undeveloped areas gravitates to Bronte Creek.

Sour water is collected, stripped through a two stage steam stripper and is then fully treated in the wastewater treatment system. No acid or caustic is used in the strippers.

Ballast water is discharged into a storage tank where oil is removed. The aqueous phase and the emulsified layer go to the wastewater system.

Sanitary sewage from the various septic tanks is discharged into the process wastewater sewer and then fully treated.

The combined stream of process wastewater enters the process API separator where the oil is manually skimmed. The oily water goes to a Tilted Plate Interceptor (TPI) and the oil is pumped to a Wet Oil Tank. The separated water is returned to the API separator and, with the effluent, is pumped to the equalization basins.

Three equalization basins provide storage for fluctuations in flow, contaminants, and temperature. Under normal circumstances, flow is only through the first basin where three mechanical mixers operate to prevent settling. Two basins are maintained for emergency storage for excess wastewater from storms, spills, or process shutdowns. All basins are lined to prevent groundwater contamination. Ballast water is combined with process waters in the equalization basin (or later in the Induced Air Flotation separators).

Water from the mixed equalization basin flows to a sump and is then pumped into the Induced Air Flotation (IAF) oil water separators. To aid in the separation of emulsified oil and solids from the process wastewaters in the IAF units, a polyelectrolyte is injected into the water. Mechanical aerators introduce air as fine bubbles inside the IAF unit to float the oil and solids to the surface. The float is skimmed and discharged back to the API separators.

Next, the effluent flows to aeration tanks for biological treatment. Oxygen is supplied through porous dome diffusers placed off the bottom of the tanks and micro-organisms feed on the organics. The wastewater and activated sludge then flow to the clarifiers where the sludge is allowed to settle. The sludge from the clarifiers is either returned to the aeration tanks or wasted to the aerobic digester. In the digester, the sludge is aerated, allowed to settle, and then landfarmed.

The effluent from the clarifiers enters a polishing basin where four mechanical aerators provide aeration and mixing. The effluent is next pumped to dual media filters (sand and anthracite) to remove suspended solids. Finally, the filtrate flows to the surge lagoon and is discharged to Lake Ontario. The backwash water from the filters is returned to the aeration basin.

For odour control in the process wastewater treatment system, air exhausted from the IAF units, aeration tanks and the thickener tank (for oily sludge) is collected, ducted through an air scrubber, and emitted through an exhaust stack.

The Catalytic Reformer uses a caustic scrubber to absorb and neutralize the gases produced during the regeneration of the platinum based catalyst in the reactors. The aqueous phase is discharged to the wastewater treatment system.

10.8.2 Sampling and Monitoring Frequency

Routine wastewater effluent sampling is summarized below.

Parameter	Grab Sampling	Composite Sampling
Oil & Grease		3/w
Suspended Solids		3/w
Ammonia pH		3/w
PH		1/d
Phenolics		1/d
Sulphides	3/w	
TOC		3/w
Fish Toxicity	1/m	
Flow		Continuous

10.8.3 Summary of MISA Process Effluent Results for 1989

The following results were obtained during the 12 month MISA monitoring program.

Priority Pollutants Found in Process Effluent
Petro Canada Oakville, Ontario
MISA Monitoring Results Dec 88 to Nov 89

Parameter	Min	Max	Avg	Unit	Loading Kg/day	Avg Concen. 1989 mg/L	Ont. Object. mg/L
1,1,2-Trichloroethane	.00	.86	.07	ug/L	.00		
1,1-Dichloroethylene	.00	2.17	.31	ug/L	.00		
1,2,3,4-Tetrachlorobenzene	.00	.20	.10	ug/L	.00		
1,2-Dichloropropane	.00	3.90	1.20	ug/L	.01		
1-Methylnaphthalene	.00	1.53	.13	ug/L	.00		
2,4-Dimethylphenol	.00	8.14	1.29	ug/L	.01		
2-Methylnaphthalene	.00	42.50	3.68	ug/L	.02		
4-Chloro-3-methylphenol	.00	4.22	.35	ug/L	.00		
4-nitrophenol	.00	2.40	.20	ug/L	.00		
Acenaphthene	.00	4.00	.35	ug/L	.00		
Acenaphthylene	.00	.80	.07	ug/L	.00		
Aluminum	.00	434.00	177.75	ug/L	.87		
Ammonia plus Ammonium	1.10	23.10	4.84	mg/L	23.70	4.84	10
Anthracene	.00	.54	.16	ug/L	.00		
Antimony	.00	1.20	.62	ug/L	.00		
Arsenic	5.00	34.00	15.98	ug/L	.08		
Benzene	.00	55.40	.80	ug/L	.00		
Bis(2-ethylhexyl) phthalate	.00	3.07	1.53	ug/L	.01		
Bromomethane	.00	19.80	4.22	ug/L	.02		

Priority Pollutants Found in Process Effluent
Petro Canada Oakville, Ontario
MISA Monitoring Results Dec 88 to Nov 89

Parameter	Min	Max	Avg	Unit	Loading Kg/day	Avg Concen. 1989 mg/L	Ont. Object. mg/L
COD	63.00	269.00	103.83	mg/L	508.52	103.83	200
Cadmium	.00	1.00	.08	ug/L	.00		
Chloromethane	.00	13.80	4.76	ug/L	.02		
Chromium	17.00	690.00	88.55	ug/L	.43	0.089	1
Chrysene	.00	.33	.03	ug/L	.00		
Cobalt	.00	75.00	8.75	ug/L	.04		
Copper	.00	8.00	.67	ug/L	.00	0.00067	1
Cyanide Total	.00	.01	.01	mg/L	.05		
DOC	8.80	72.00	17.91	mg/L	87.72		
Ethylbenzene	.00	3.18	.03	ug/L	.00		
Fluorene	.00	4.42	.37	ug/L	.00		
Hexachlorobezene	.00	.10	.05	ug/L	.00		
Hydrogen ion (pH)	7.20	9.00	8.04				
Lead	.00	12.00	2.00	ug/L	.01	0.002	1
Methylene chloride	.00	.85	.13	ug/L	.00		
Molybdenum	9.00	116.00	29.50	ug/L	.14		
Naphthalene	.00	1.28	.11	ug/L	.00		
Nickel	3.00	16.00	6.18	ug/L	.03	0.006	1
Nitrate + Nitrite	.13	.47	.26	mg/L	1.27		
Octachlorodibenzo-p-disoxin	.07	.65	.36	ng/L	.00		
Octachlorostyrene	.00	.14	.07	ug/L	.00		
Oil and grease	.00	18.20	2.45	mg/L	12.00	0.002	10
PCBT	.00	5200.00	2600.00	ng/L	.01		
Phenanthrene	.00	2.83	.24	ug/L	.00		
Phenol	.00	9.56	1.47	ug/L	.01		
Phenolics (4AAP)	8.00	296.00	42.36	ug/L	.21	0.042	0.02
Pyrene	.00	.52	.12	ug/L	.00		
Selenium	.00	13.60	5.37	ug/L	.03		
Silver	.00	3.00	.67	ug/L	.00		
Stryene	.00	1.26	.26	ug/L	.00		
Sulphide	.04	.40	.17	mg/L	.83		
TOC	13.00	100.00	26.95	mg/L	131.99		
Toluene	.00	33.80	.47	ug/L	.00		
Total Kjeldahl nitrogen	1.51	19.50	6.64	mg/L	32.52		
Total PCDF	.00	.02	.01	ng/L	.00		
Total TCDF	.00	.07	.04	ng/L	.00		
Total phosphorus	.00	3.68	.77	mg/L	3.77		
Total suspended solids	5.00	191.00	22.34	mg/L	109.41	22.34	15
VSS	4.00	47.00	14.51	mg/L	71.07		
Zinc	.00	31200.00	1402.03	ug/L	6.87	1.40	1
m-Cresol	.00	1.00	.14	ug/L	.00		
m-Xylene and p-Xylene	.00	62.20	1.00	ug/L	.00		
o-Cresol	.00	2.35	.42	ug/L	.00		
o-Xylene	.00	101.90	4.03	ug/L	.02		
p-Cresol	.00	1.90	.32	ug/L	.00		

Avg daily process flow 4,897.658 m^3/day

10.9 Comparison of Process Effluent Quality with Ontario Effluent Quality Objectives (OEQO)

The concentration levels of phenolics, total suspended solids, zinc, COD, oil and grease exceeded the Ontario Objectives in 1989. Since 1989 the plant has discontinued the use of zinc chromate chemicals for cooling water treatment and zinc is no longer a problem. On a yearly average basis the concentration levels for phenolics, total suspended solids and zinc were not met. On three occasions in 1989 the process effluent showed acute toxicity to Rainbow Trout and Daphnia Magna. This toxicity was ascribed to elevated levels of zinc used in the recirculated water system.

The low water use also tends to concentrate the contaminants in the wastewater.

10.9.1 Comparison with U.S. EPA BPT/BAT Limitations (see Table X)

During 1989 the following number of exceedences would have occurred if the U.S. BAT/BPT limitations had been applicable.

Daily maximum limit	•	Total Suspended Solids	11
	•	Oil and Grease	1
	•	Sulphides	9
30 day average limits	•	Total Suspended Solids	3
	•	Sulphides	5

10.10 Fundamental Factors Affecting Effluent Quality

The very low rates of process wastewater to feedstock charge makes it more difficult for the refinery to meet concentration limits set by Ontario. The refinery is therefore at some disadvantage when compared with higher water users. A regulation based on loadings would be more desirable.

During the early part of 1990 zinc chromate chemicals were discontinued for recirculated cooling water control. Zinc at levels above 1 mg/L is known to be very toxic and this is probably the reason for the toxicity in 1989. As the system is flushed out zinc should no longer be a problem but this may take time.

As indicated previously in Section 10.9 the wastewater treatment system cannot handle all of the storm water resulting in high suspended solids in the effluent from colloidal clay particles. The problem is by no means limited to this refinery. Some recognition of the fact that non volatile suspended solids from surface run off are not harmful may have to be given. Improvement is under investigation.

10.11 Control Orders Issued

None outstanding.

10.12 Capital and Annual Operating Costs for Wastewater Treatment System

The refinery has spent approximately $25 million (in 1989 dollars) from 1970 through 1989 on the wastewater treatment system. $10 million were spent in 1989 alone on the upgraded system mentioned previously.

Annual operating costs for labour, maintenance, utilities, chemicals, etc. were not available from the refinery.

10.13 Best Management Practices

10.13.1 Training

Operators are trained under an informal on-the-job training program and each operator receives a manual with written daily guidelines. The operators also attend seminars and receive one-on-one training at the plant from chemical suppliers. In approximately one year, MOE certification for operators is anticipated.

10.13.2 Manuals

All operators have a copy of the operating manual with instructions for identifying and correcting upsets in the wastewater treatment system.

10.13.3 Specifications

Within the manual are operating specifications for the design and normal operating conditions of each module in the plant.

10.13.4 Responsibility/Authority

The overall responsibility for operation of the plant falls under the area supervisor. After normal working hours, the shift superintendent has the responsibility to solve any problems or contact the appropriate personnel.

Personnel with partial or full responsibility for the plant include the operators, shift superintendent, process engineers, and the environmental engineer. In addition, area supervisors from within the refinery attend a daily operators meeting where wastewater treatment issues are discussed.

10.13.5 New Projects

During the conceptual stage of new projects, the project engineer will informally discuss relevant issues with the environmental staff. Then, prior to final approval, the environmental engineer is required to sign-off on the projects.

Wastewater treatment repairs and new projects are ranked and assigned priority status as required. Overtime work is authorized as necessary for critical projects.

Work is completed (1989) on the major upgrade of the wastewater treatment plant. Formal one and five year plans have also been developed for future upgrades.

Other improvements for the system which are under investigation include the following:

- using sour water stripper bottoms as desalter make-up water;
- improving wastewater segregation;
- increasing employee awareness;
- eliminating storm water originating from areas outside the refinery perimeter;
- using a reboiler on SWS;
- changing sample collection system to return samples to slop;
- revamping condensate collection system;
- continue identifying methods for wastewater flow reductions.

10.13.6 Oil Spills in Plant

The plant has a formal spill response program. Equipment on-site for spill clean-up includes a trailer with pumps, vacuum truck, 1700 feet of boom, and an oil spill boat. In addition, under a mutual agreement with other plants, 2 boats are available at Clarkson. A Spill Coop with the Port of Hamilton has available a boat, boom, and truck. In the event of a spill, Petro-Canada has a contract already in place with a company on retainer to expedite an emergency cleanup. During 1989, two liquid "spills" inside the plant were reported to the Ministry of the Environment. One involved about 100 barrels of gasoline and the in the other some oil was found in the ground water surrounding an excavation.

10.13.7 Landfarming

Waste landfarmed on-site includes API separator bottoms, digester sludge and tank bottoms. The landfarm is on clay in a bermed area. No leachate collection system exists. All loads to the landfarm are formally recorded in a log book.

10.14 Conclusions

The treatment of wastewater at the refinery has a high priority as evidenced by the commitment of $10 million in 1989 for plant upgrades. Although not reflected in the 1989 MISA monitoring data, significant improvements have occurred in 1990.

The plant generates a low ratio of wastewater to feedstock. This low water use is very good considering the fact that the plant was built in 1958 at a time when much of our present technology was unknown to the industry. At the same time this low water usage tends to penalize the plant since Ontario Effluent Quality Objectives are concentration based. During 1989 control over zinc used in the recirculated cooling water system was erratic as evidenced by three fish kills.

The plant has installed an elaborate vapour collection system for off gases coming from the induced air flotation unit and the biological treaters. This system prevents the emission of oily vapours other gases into the atmosphere. Such a system is not common practice in the industry and is commendable.

10.15 APPENDIX

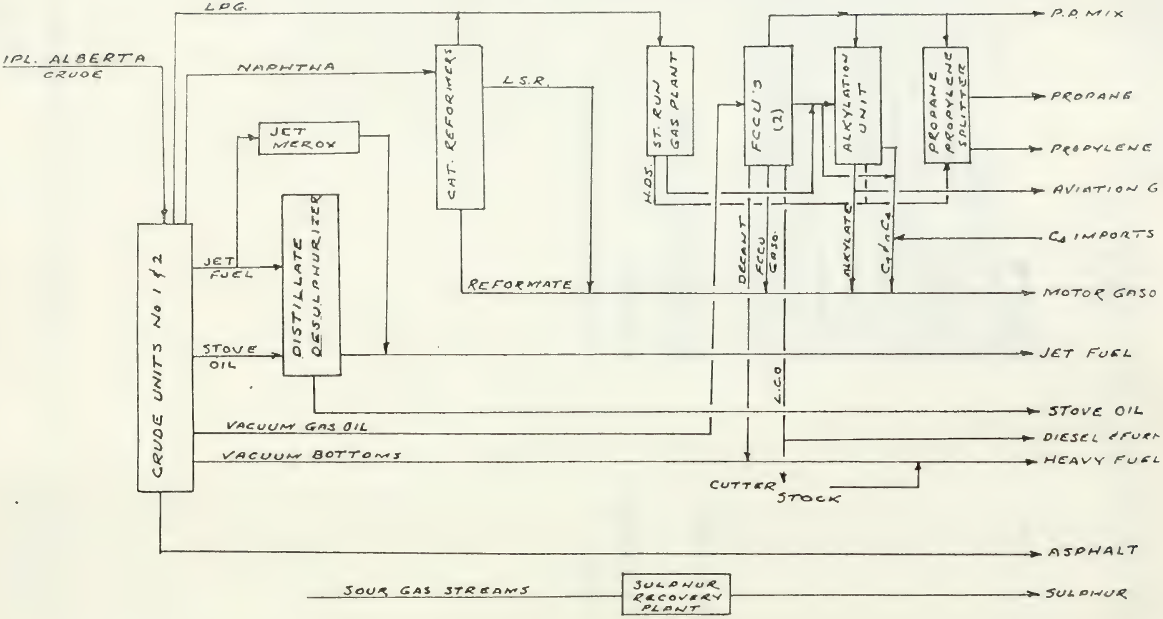
- chemical used
- process flow schematic
- waste water schematic

CHEMICALS USED

Cooling Tower	-	SULPHURIC ACID CHLORINE CUSTOM-COOL 3C65 - Corrosion and deposit inhibitor (Sodium hydroxide, Sodium tolyltriazole) ACTI-BROM 1338 - Chlorine enhancer and biodispersant (Sodium bromide) NALSPERSE 7348 - Liquid cooling water biodispersant (Polyoxypropylene/polyoxyethylene) ALCHEM 7330 - Cooling water slimicide (5-chloro-2-methyl-4-isothiazoline-3-one, 2-methyl-4-isothiazoline-3-one, Magnesium nitrate) ALCHEM 71-D5 - Antifoam (polyglycols, fatty acids, polyglycol ester and oxyalkylate, mineral seal oil, kerosene, stearic acid) ALCHEM 7308 - Cooling water dispersant (Nonylphenoxypolyethoxyethanol, Polyoxypropylene polyoxyethylene)
Water Treatment	-	PHOSPHORIC ACID POLYELECTROLYTE (Demulsifier) POLYELECTROLYTE (Flocculant)
Dual-Media Filter	-	ANTHRACITE
Scrubber	-	ALKALINE SODIUM HYPOCHLORITE

PETROCANADA OAKVILLE REFINERY

PROCESS FLOW SCHEMATIC



11.0 CURRENT STATUS OF PETRO-CANADA'S MISSISSAUGA REFINERY

11.1 Plant Description

Petro-Canada's Lake Ontario Refinery in Mississauga, Ontario was built in 1943 by British American Oil Company Limited under war time conditions. It is located on 411 acres of land, 84% of which has been developed. The main purpose of the plant is to make industrial and automotive lubricants as well as a full line of greases. This is a specialized refinery producing a specialty of products. Blended finished gasoline and other products (see list) are also produced. Catalytic cracker feed and isomerate are shipped to the Oakville refinery. Isomerate feed is received from the Oakville plant and processed at Mississauga when it is charged to the Isomerization Unit.

The saleable products of the plant are:

- gasolines
- industrial aliphatic solvents
- propane
- jet fuel
- stove oil
- diesel fuel
- lube oils (industrial & automotive)
- greases
- asphalt
- slack wax
- sulphur

11.1.1 Refinery Process Data

Note: All data is in M^3/day.

Process	1989 Stream Day Capacity	1989 Calendar Day Capacity	Year Installed
Crude Unit	7150	6653	1957
Crude Desalting	7150	6653	1957
Vacuum Distillation	6120	2269	1957
Solvent Deasphalting (PDA)	790	473	1977
Catalytic Reforming	1590	1206	1973
Hydrogen Treating	3000	2405	
Reformer HDS			1973
Isom. HDS			1988
Isomerization	1193	984	1988
Lube Oil Processing	1750	1481	1977
Asphalt Oxidation	---	242	1944
Hydrogen Plant (1000 m^3/day)	410	93.2	1977
Aliphatic Solvents	N/A	189	1957
Distillate Desulphurizing	950	795	1959
Saturated Gas Plant	N/A	1739	1957
Lubes - Dewax	1110	971	1977

11.2 Feedstocks Run in 1989

In 1989 five different crude feedstocks were run as follows:

Name	% Run	% Sulphur	API Gravity
Lube Crude	68.9	0.36	38.6
IPPL #1	4.3	0.45	38.0
Bow River	22.7	2.2	26.4
Cold Lake	2.2	2.9	24.8
Lloyd Blend	1.9	2.8	24.8

All of the crude comes from Western Canada.

11.3 Chemicals Used

See appendix in Section 11.15.

11.4 Water Management

11.4.1 Water Supply

Intake water for the plant is drawn from Lake Ontario. The average annual flow rate is 166,280 M^3/day. The plant also purchases 327 M^3/day of potable water from the municipality. Lake water temperature is normally well below 15°C (60°F). The water is lightly chlorinated for algae control.

11.4.2 In Plant Reuse and Recycling Techniques

Overhead condensate from the Crude Unit Vacuum tower is reused in the desalter as make up. The remaining 436 M^3/day of condensates from other sources is not recycled but goes to the wastewater treatment system.

Spent sulphidic caustic is disposed of in two ways. About 3.5 M^3/day of 3% caustic goes to the wastewater treatment while another 1.8 M^3/day of 3% caustic is injected into the crude downstream of the desalter to neutralize the HCl. Phenolic caustic goes to the biotreater. In the past the material was shipped to pulp and paper companies as well as to a phenolic resins plant in the U.S.A.

The refinery continuously regenerates catalyst on the Catalytic Reforming Unit. The catalyst is continuously withdrawn to a regeneration tower where the coke and other contaminants are burned off in a low oxygen atmosphere. Next it is subjected to a high oxygen atmosphere. It is then subjected to a nitrogen purge. Before returning to the reactor. A chlorinated hydrocarbon is injected into the regenerator to condition the catalyst.

11.4.3 Ratio of Wastewater to Feed Charge

Based on the 1989 Crude charge rates the refinery produced 1641 M^3 of process wastewater for each 1000 M^3 of feedstock. the refinery produced 57.5 Canadian gallons of process wastewater per barrel of crude. This includes storm water runoff from the older process areas.

In terms of Federal Regulations and Guidelines the ratio is 39.9 Canadian GPM per 1000 BPD. The refinery may be considered a fairly high water user.

11.4.4 Cooling Methods Used

Cooling for the Mississauga Refinery is provided by cooling towers (69%), by once through cooling water (22%), and by air cooling (9%). The recirculated water in the cooling towers is treated by a zinc-chromate system and operates at 4 to 5 concentration cycles.

11.5 Segregation of Sewer Systems

1. *Sour Water*

   Sour water is collected in a closed system from the lube oil hydrotreater, the hydrogen desulphurization unit, bottoms from slop tanks and other smaller sources at the rate of 436 M^3/day.

2. *Process Wastewater*

   This includes desalter effluent, ballast water, mixed media filter back wash, stripped sour water, storm water from the older process areas, process units, spent sulphidic caustic, sanitary sewage and occasionally cooling tower blow down.

3. *Storm Water*

   Storm water from the remaining developed areas is stored in one of two large basins. Storm water falling on process areas in the older part of the refinery goes directly to the process water treatment plant.

4. *Once Through Cooling Water*

   OTCW flows to two API separators and then to the lake through two separate outfalls.

5. *Ballast Water*

   Ballast water is pumped to a storage tank, the oil is removed and the water flows to the wastewater treatment system.

11.6 Sources of Wastewater

The total flow of process wastewater as measured by the MISA program in 1989 averaged 10917 M^3/day.

A number of specific sources of wastewater have been singled out because they may offer an opportunity for flow reduction.

	M^3/day	Source
Ballast water	33	
Boiler blow down 365	Goes to OTCW	
Cooling tower blow down	485	By-passes wastewater treatment system to final effluent
Storm water from process areas (estimated)	2420	
Storm water from developed areas		
Desalter water	500	
Stripped sour water	436	
Pump cooling glands	382	To process wastewater
Compressor cooling glands	190	To process wastewater
Pump and compressor cooling glands	2469	To OTCW
Blow down from water treatment	N/A	

11.7 Opportunities to Reduce Wastewater Flow

Most of the wastewater comes from the process units so it would require a complete water balance to determine all of the candidates for possible flow reduction.

The stripped sour water should be reconsidered for possible re-use in the crude desalter although there may be good reasons why this is not advisable. The pump and compressor cooling glands water discharging into the process wastewater system should be considered a possible candidate using a closed water system of some kind. A large amount of once through water is being used to cool a number of pump and compressor glands, and this water is being returned to the once through system. This practice does not add to the process wastewater but increases the possibility of contaminating the once through water.

11.8 Description of Wastewater Treatment System

11.8.1 Discussion of Schematic

Process wastewaters from the plant first pass through an API oil separator to remove suspended solids and oil. The effluent is pumped through one of three parallel sand filters and then into an equalization basin. Backwash from the filters flows to a sludge holding basin where the water settles out and is returned to the API separator. The sludge is landfarmed. Within the equalization basin, the water is mixed and the pH is adjusted as necessary. The effluent next flows to the aeration tanks in the biological treatment plant. Turbine mixers and a sparging system mix the bacteria, water, and oxygen in the tank. The wastewater and activated sludge pass on to clarifiers where the effluent and sludge are separated. The effluent is combined with once through cooling water and discharged into Lake Ontario. The sludge is returned to the biological treatment plant or wasted in the digester and finally landfarmed.

Ballast water is collected and stored in a holding tank and then treated in the API separators, sand filters and the biological treatment system.

Cooling tower blowdown is not treated as a rule but is discharged directly to the final effluent; however, it can be treated in the biological treatment plant.

Once through cooling water flows through two API oil separators and is then discharged to the lake.

Storm water falling on the older sections of the process area is collected and goes directly to the wastewater treatment system. A twin basin collection system handles the remainder of the water from most of the tank farms, roads, ditches, and the newer lube process units. The water flows through an oil separator then into the first holding basin to remove oil and suspended solids. Oil is skimmed and the water is normally pumped to the wastewater treatment system. During extreme rainfall the second basin is available to handle the overflow of a once in 5 year storm.

Sour water goes through a closed oil separation tank then to a single stage steam stripper and then to the wastewater treatment system.

Sanitary sewage is collected in a septic sedimentation tank and the liquids go to a Foul Condensate equalization tank and then into the process wastewater treatment system.

11.8.2 Sampling and Monitoring Frequency

The wastewater treatment plant final effluent receives composite sampling three times per week for oil and grease, ammonia, and sulphides. Daily composite samples are taken for suspended solids, pH, phenols. Flow is monitored continuously and a fish toxicity test is done once per month.

A composite sample of once through cooling water is tested once per week for oil and grease as well as phenols. The flow from No. 3 trap (OTCW) is monitored continuously while the flow from Trap No. 1 (OTCW) is checked three times per week.

11.8.3 Summary of MISA Process Effluent Results for 1989

On the following page, data results from the 12 month Misa monitoring program. A number of priority pollutants were found, most at very low levels.

11.9 Comparison of Process Effluent Quality with Ontario Effluent Quality Objectives (OEQO)

On a concentration basis this refinery did not meet the objectives for total suspended solids, oil and grease, zinc and phenolics on a regular basis. Average concentrations of total suspended solids were considerably above the OEQO.

11.9.1 Comparison with U.S. EPA BPT/BAT Limitations (see Table X)

During 1989 the following number of exceedences would have occurred if the U.S. EPA BPT/BAT limitations had been applicable.

Daily maximum limits	• Total Suspended Solids	84
	• Oil and Grease	7
	• Ammonia	9
	• Sulphides	17
	• Total Chromium	2
30 day average limits	• Total Suspended Solids	7
	• Oil and Grease	3
	• Ammonia	3
	• Sulphides	5
	• Total Chromium	4

Priority Pollutants Found in Process Effluent
Petro Canada Inc., Lake Ontario Refinery - Mississauga Plant
Misa Monitoring Data Dec 1988 to Nov 1989

Parameter	Min	Max	Avg	Unit	Loading Kg/day	Avg Concen. 1989 mg/L	Ontario Objective mg/L
Aluminum	65.00	620.00	267.45	ug/L	2.92		
Ammonia + Ammonium	.00	70.00	3.75	mg/L	40.96	3.75	10
Antimony	.90	3.10	1.62	ug/L	.02		
Arsenic	2.00	12.00	5.36	ug/L	.06		
Benzene	.00	1.69	.04	ug/L	.00		
COD	20.00	84.00	44.08	mg/L	481.47	44.08	200
Cadmium	.00	9.00	.82	ug/L	.01		
Chloroform	.00	14.60	2.63	ug/L	.03		
Chromium	.00	550.00	125.95	ug/L	1.38	.126	1
Cobalt	.00	5.00	1.09	ug/L	.01		
Copper	.00	8.30	3.39	ug/L	.04	.003	1
DOC	4.00	46.50	12.65	mg/L	138.17		
Dibromochloromethane	.00	1.01	.08	ug/L	.00		
Hydrogen ion (pH)	6.60	9.20	7.44				
Lead	.00	230.00	23.09	ug/L	.25	.023	1
Mercury	.00	.15	.04	ug/L	.00		
Methylene chloride	.00	13.55	1.13	ug/L	.01		
Molybdenum	5.00	110.00	35.00	ug/L	.38		
Nickel	3.00	11.00	7.51	ug/L	.08	.007	1
Nitrate + Nitrite	.04	3.41	.59	mg/L	6.44		
Oil and grease	.00	18.70	4.48	mg/L	48.93	4.48	10
Phenanthrene	.00	.64	.06	ug/L	.00		
Phenolics (4AAP)	.00	71.00	8.75	ug/L	.10	.009	.02
Pyrene	.00	.63	.06	ug/L	.00		
Selenium	.00	2.50	1.10	ug/L	.01		
Silver	.00	3.00	.45	ug/L	.00		
Styrene	.00	1.44	.17	ug/L	.00		
Sulphide	.00	.87	.10	mg/L	1.09		
TOC	3.70	56.00	19.45	mg/L	212.45		
Thallium	.00	310.00	80.82	ug/L	.88		
Toluene	.00	1.06	.02	ug/L	.00		
Total Kjeldahl nitrogen	.60	5.18	1.99	mg/L	21.74		
Total phosphorous	.00	3.10	.20	mg/L	2.18		
Total suspended solids	4.70	551.20	26.15	mg/L	285.63	26.15	15
VSS	.00	391.20	15.39	mg/L	168.10		
Vanadium	.00	140.00	48.09	ug/L	.53		
Zinc	.00	1270.00	91.23	ug/L	1.00	0.91	1
m-Xylene and p-Xylene	.00	22.00	.43	ug/L	.00		
o-Xylene	.00	20.50	.50	ug/L	.01		

Avg daily process flow 10,922.691 m^3/day

11.10 Fundamental Factors Affecting Effluent Quality

The Mississauga Refinery is the second oldest in Ontario and was built during World War II when there was a chronic shortage of materials. As a result the refinery has suffered ever since from the lack of proper sewage segregation. Although much effort has been made to eliminate cross connections and to redesign the sewer systems some of the original deficiencies remain.

All units built since 1977 are on recirculated cooling water or air cooling as a matter of policy. Prior to that time only large volumes of once through water was used. While most of the cooling today is by means of recirculated water this is mainly because a large part of the original plant was shut down in 1984.

During heavy rainfall the wastewater treatment plant is called upon to handle large volumes of run off from the process areas. This may disturb the equilibrium in the biotreater and may cause variability in treatment.

The large Compounding Blending and Grease Plant may add a significant number of soluble contaminants, of which some may be difficult to treat.

11.11 Control Orders Issued

None outstanding.

11.12 Capital and Annual Operating Costs for Wastewater Treatment System

The refinery reports spending $17.6 million in 1989 dollars since 1970 on wastewater treatment.

Annual operating costs are not available.

11.13 Best Management Practices

11.13.1 Training

New employees receive 2½ weeks of formal training with manuals and then 3 weeks of on-the-job training at the wastewater treatment plant before being assigned to a shift. In addition, six plant personnel are scheduled to attend a wastewater treatment technology course at Lambton College. MOE operator certification is pending.

11.13.2 Manuals

The operator's manual includes information and procedures for operation of units and areas such as the activated sludge plant, sand filter, storm basins, and foul condensate facilities.

11.13.3 Specifications

Within the wastewater treatment plant facility is a lab specifically used for testing and monitoring the effluents from individual process units within the plant. Process information and test results are recorded on a daily log as well as on the Shift Report which provide quick check tools for operators and environmental personnel to detect upsets in the plant. Established guidelines for test data are used to evaluate the plant's efficiency.

11.13.4 Responsibility/Authority

Directly responsible for the operation of the plant are the Utilities Superintendent and Utilities Master. The Shift Superintendent is responsible for trouble shooting operations problems and will call in management and/or staff as necessary.

Additionally, operators of the refinery units share in the responsibility for waste water and the Environmental Co-ordinator and Technical Service Engineers provide support as needed.

11.13.5 New Projects

The Environmental Co-ordinator becomes involved informally during the development of new projects. Formal approval is later required when applying for Certificates of Approval.

Priority to maintenance projects for the plant is given when exceedences in effluent contaminant limits occur. Overtime work is authorized if required.

Formal one and five year plans exist for upgrading the wastewater treatment system and the Environmental Co-ordinator participates in budgeting and planning meetings.

11.13.6 Oil Spills in Plant

The plant has a formal spill response program. On-site equipment includes a vacuum truck, pumps, etc. In addition, contract personnel are available on a 24 hour basis. A mutual agreement exists for further assistance and the plant is a member of the Hamilton Harbour spill Control Group which has available two work boats, a boom and other equipment.

During the 1989 year, the Mississauga Plant reported to the Ministry of Ontario two land spills inside the plant and three water spills at the dock. The largest spill outside of the plant occurred at the dock when 5 barrels of diesel oil were released.

11.13.7 Landfarming

Oily sludge and digester sludge is landfarmed on-site. The landfarm covers approximately 15 acres. The areas is bermed to prevent runoff. Collected runoff is trucked to the wastewater treatment system. Ground water wells are monitored twice per year to ensure there is no ground water contamination.

11.14 Conclusions

This is an old plant except for some new units built since 1977. Petro Canada refines most of its saleable products at Oakville. The modern lube processing facilities plus the very large modern Compounding Blending and Grease Plant probably justifies its continued operation.

Since installation of a modern biological treatment unit in 1982 there has been a big improvement in wastewater quality. The water use however is high in comparison with other similar plants.

11.15 APPENDIX

- chemical used
- process flow schematic
- waste water schematic

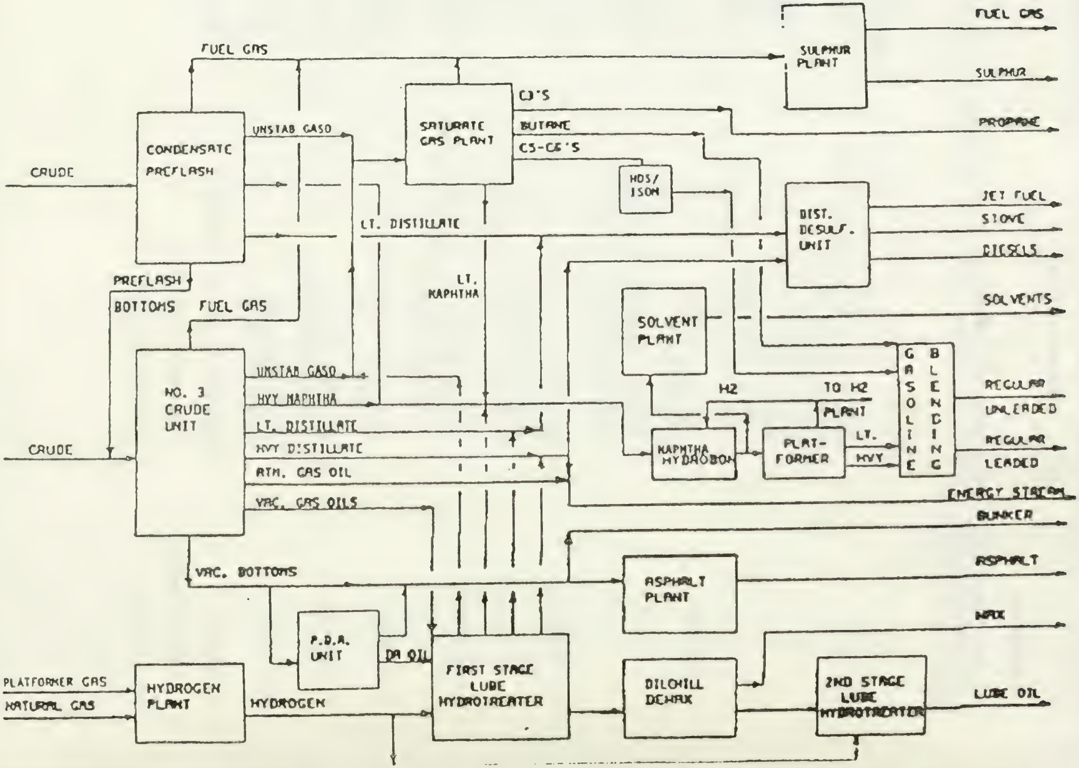
CHEMICALS USED

Unit Additives

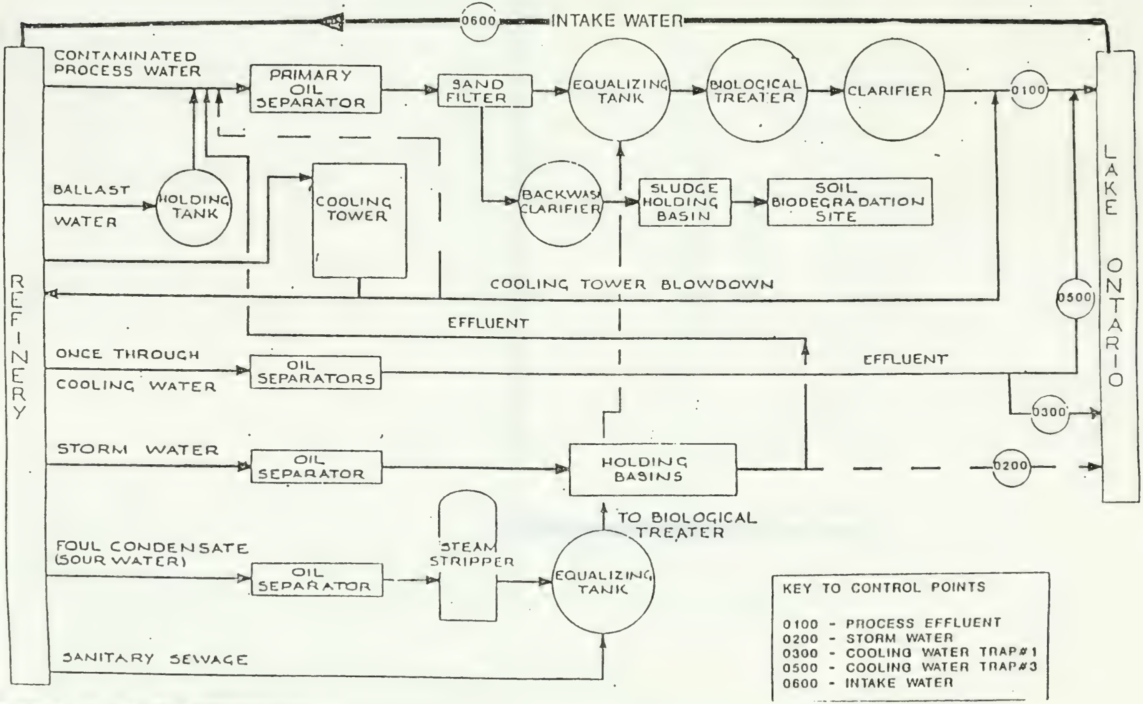
List given is for process chemicals being used as of Sept/88 in process unit areas for corrosion control and demulsifying. Only those chemicals that would normally end up in water effluent to the treatment plant are listed:

			Annual Consumption
Crude Unit	-	NEUTRALIZING AMINE (Alchem 5196) (includes asphalt plant)	2000 IG
		AQUA AMMONIA	
		LIQUID CAUSTIC SODA (50 Be')	95000 IG
		ALCHEM 169	1700 IG
		MEROX (Cobalt Chelate)	1100 lb
		DEMULSIFIER (Alchem 10AL5841)	2100 IG
Utilities Plant	-	SODIUM CHLORIDE	1.2 M lb
		DEARBORN 3171	10 K lb
		LIME	500 K lb
		SLUDGE CONDITIONER DEARBORN	10 K lb
		ANHYDROUS DISODIUM PHOSPHATE	10 K lb
		SODIUM SULPHITE	35 K lb
Cooling Towers	-	CHLORINE	14 K lb
		SULPHURIC ACID	80 K lb
		DISPERSANT (Betz 434)	10 K lb
		CORROSION INHIBITOR (Betz 39A)	11 K lb
Asphalt Plant	-	FERRIC CHLORIDE	30 K IG
		NEUTRALIZING AMINE (Alchem 5196) (including crude unit)	2000 IG
Dewax Unit	-	METHYL ETHYL KETONE	72000 Gal
		TOLUOL	33000 Gal
Hydrogen Plant	-	DIETHANOLAMINE (includes sulphur plant)	72000 lb
Sulphur Plant	-	DIETHANOLAMINE (includes sulphur plant)	72000 lb
Hydrotreater	-	INHIBITOR KROM TROL X5 (Betz)	4200 lb
Pumping and Shipping	-	COMMERCIAL ALCOHOL	0
Water Treatment	-	PHOSPHORIC ACID	0

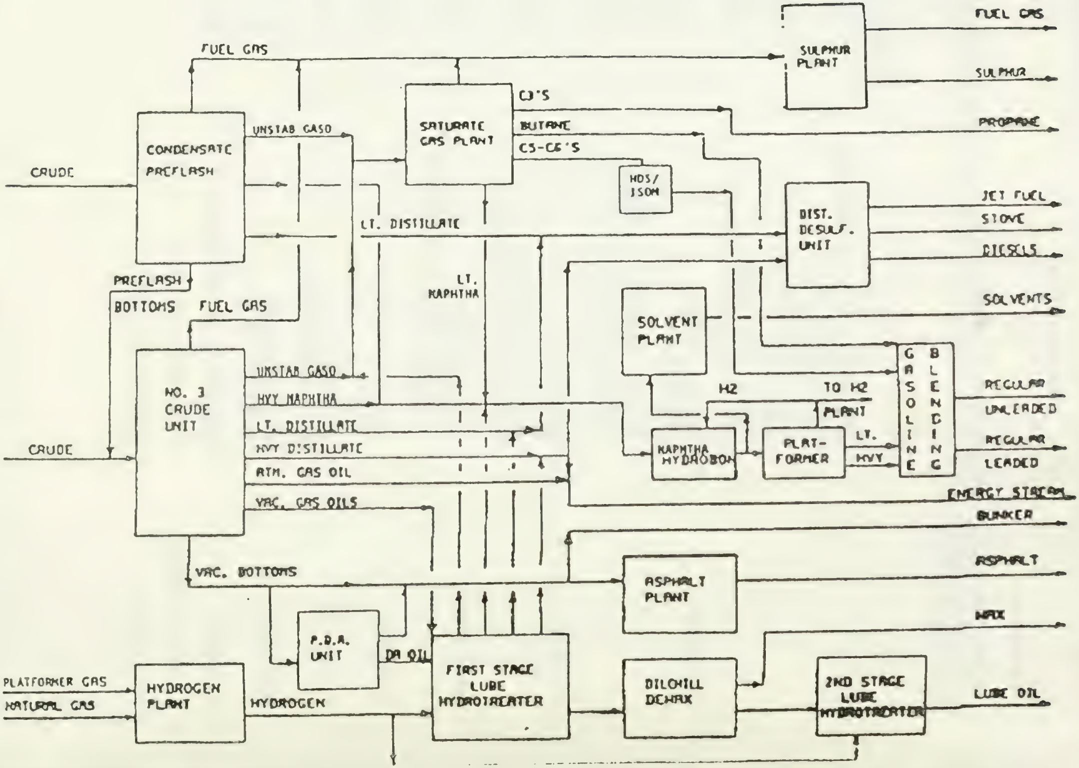
LAKE ONTARIO REFINERY
MISSISSAUGA PLANT



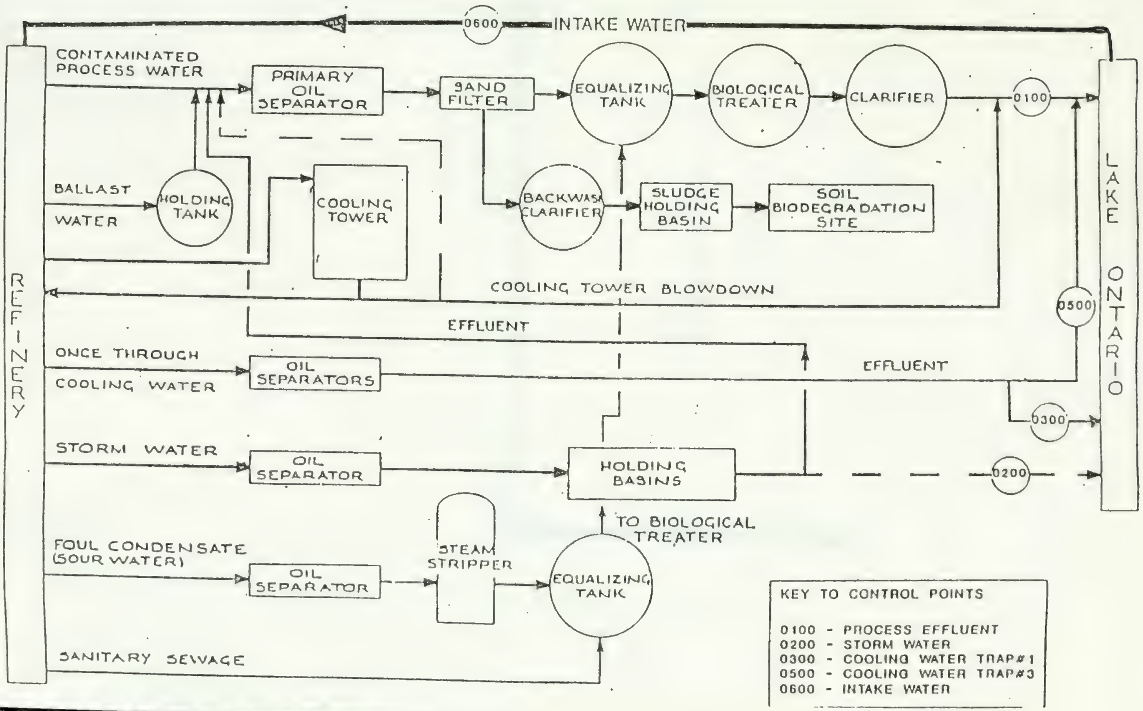
PETRO-CANADA PRODUCTS
LAKE ONTARIO REFINERY - MISSISSAUGA PLANT
WASTEWATER TREATMENT SYSTEM



LAKE ONTARIO REFINERY
MISSISSAUGA PLANT



PETRO-CANADA PRODUCTS
LAKE ONTARIO REFINERY - MISSISSAUGA PLANT
WASTEWATER TREATMENT SYSTEM



APPENDIX

QUESTIONNAIRE

QUESTIONNAIRE

ON

STATUS OF WASTE WATER GENERATION AND TREATMENT IN ONTARIO PETROLEUM REFINERIES

FOR

A REPORT TO BE SUBMITTED TO THE MISA PETROLEUM
REFINING SECTOR JOINT TECHNICAL COMMITTEE

BY

SCIENCE APPLICATIONS INTERNATIONAL CORPORATION
IN ASSOCIATION WITH
AMENDOLA ENGINEERING INC.
APOGEE RESEARCH INTERNATIONAL LTD.

SEPTEMBER 1990

GUIDELINES FOR QUESTIONNAIRE COMPLETION

GENERAL

- Please print clearly. Typing is not necessary.
- Feel free to add additional information not requested if your believe it is relevant to understanding.
- If a question is not applicable use N/A.
- If the information is not available use N/AVL.
- Use available information as much as possible from your existing files.
- If information is not available from files use your best estimate but indicate as such.
- 1989 Stream Day Capacity means the design or rated capacity of the process unit not the rate being run.
- 1989 Calendar Day Rate means the total volume run during the year divided by the number of operating days.
- The sample BLOCK FLOW DIAGRAM is intended to indicate only the level of detail required.

Refinery Name ____________________

Location ____________________

Mailing Address ____________________

____

Telephone Number ____________________

Fax Number ____________________

Name of Contact Person ____________________

Job Title ____________________

A. REFINERY PROCESS DATA

Please include a simple process block flow diagram of the refinery operations with this questionnaire.

Indicate below which of the processes listed below are used at your refinery.

Process		1989 Stream Day Capacity	1989 Calendar Day Rate	Year Installed
1.	Atmospheric Crude Distillation	____________	____________	____________
2.	Crude Desalting	____________	____________	____________
3.	Solvent Deasphalting	____________	____________	____________
4.	Viscosity Breaking	____________	____________	____________
5.	Fluid Coking	____________	____________	____________
6.	Delayed Coking	____________	____________	____________
7.	Thermal Coking	____________	____________	____________
8.	Fluid Cat. Cracking	____________	____________	____________
9.	Moving Bed Cat. Cracking	____________	____________	____________
10.	Hydro Cracking	____________	____________	____________
11.	Catalytic Reforming	____________	____________	____________
12.	Hydrogen Treating	____________	____________	____________
13.	Catalytic Polymerization	____________	____________	____________
14.	HF Alkylation	____________	____________	____________

15.	Sulphuric Acid Alkylation	______	______	______
16.	Isomerization	______	______	______
17.	Lube Oil Processing	______	______	______
18.	Asphalt Oxidation	______	______	______
19.	Hydrogen Plant M^3/day (Production)	______	______	______
20.	Total Sweeting Process	______	______	______
21.	Aliphatic Solvents	______	______	______
22.	BTX Extraction	______	______	______
23.	Other	______	______	______
24.	Other	______	______	______
25.	Other	______	______	______

B. FEEDSTOCKS PROCESSED IN 1989

Include condensate if significant

	#1	#2	#3	#4	#5
Name					
Origin					
API° Gravity					
%S					
% of Total Run					
Trace Metals					
Antimony					
Beryllium					
Cadmium					
Chromium					
Copper					
Lead					
Mercury					
Nickel					
Selenium					
Silver					
Thallium					
Zinc					

Note: If semi finished product is rerun in your plant please indicate below and provide relevant data if possible.

C. WASTE WATER SOURCES AND IN-PLANT TREATMENT

1. Barometrics[1] Average Flow ________________ M^3/day.

2. Sour Waters Average Flow ____________________ M^3/day.

Method of Treatment.	Check method used.
(a) Single Stage Stripping	
(b) Two Stage Stripping	
(c) Air Oxidation	
(d) Others (List)	

____

____

Sources of Sour Water	Annual Average Flow M^3/day.
(a) Condensate from Cat. Cracking	
(b) Condensate from Petroleum Coking	
(c) Condensate from Hydrocracking	
(d) Condensate from other Hydrocarbon processing	
(e) Condensate from Crude Unit	
(f) Flare Drum Knock Out	
(g) Other	
TOTAL SOUR WATER FLOW	

If certain sour water streams are not treated, list them and describe disposition, e.g. discharged, reused, etc.

____

____

____

---

[1]. Barometrics refers to any system where water is used to cool or quench hydrocarbons and comes in direct contact.

%

Disposal of treated sour water ____________________

(a) Desalter makeup ____________________

(b) Other uses (describe) ____________________

____

____

(c) Non recycled e.g. to treatment plant ____________________

Do you have any plans to upgrade the sour water treatment units in the future, if so describe and give expected completion date.

____

____

____

____

3. Spent Caustic Disposal — Annual Average Flow in M^3/day.

(a) Sulphidic

Amount oxidized ____________________

Amount neutralized ____________________

Amount sold ____________________

Other (explain) ____________________

____

____

(b) Phenolic

Amount sold ____________________

Acid oil sold ____________________

Other (explain) ____________________

____

____

4. Disposal of desalter water. Annual average flow M^3/day.

(a) Desalter effluent ______________________

(b) Describe any treatment it undergoes before going to treatment plant, e.g. flashed for H_2S removal, acidification, gravity settling.

____

____

____

____

5. Use space below to describe additional in plant treatment systems in your refinery (attach additional sheets if necessary).

____

____

____

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____

6. Scrubber solution from catalytic reformer regeneration.

a) Indicate type of catalyst regeneration system, re. batch, continuous, or spare reactors.

____

____

____

____

b) Frequency of regeneration. __________ times in 1989.

c) State type of absorbent used and volume.

____

____

d) Discuss final disposal of scrubber solution and the contaminants present in the solution.

____

____

____

____

____

____

e) Briefly describe the regeneration system used.

____

____

____

____

____

____

D. PLANT WATER MANAGEMENT

Annual Average Flow M^3/day.

1. Intake Waters ____________________

(a) Fresh Water (river or lake) ____________________

(b) Well ____________________

(c) Recycled treated wastewater ____________________

(d) Municipal ____________________

(e) Surface runoff ____________________

(f) Other ______________________________

____

If the intake water used for processing requires chemical treatment prior to use (excluding cooling towers and boiler feedwater) please indicate the annual average blowdown per day and the method of treatment.

____

____

____

____

2. Waste Waters — Annual Average Flow M^3/day

(a) Refinery process waste water ____________________

(b) Ballast water from ships ____________________

(c) Storm water treated by main treatment plant ____________________

(d) Blowdown from water treatment ____________________

(e) Boiler blowdown ____________________

(f) Cooling tower blowdown ____________________

(g) Other - please list below ____________________

____

____

3.	Cooling Service	Number of pumps	M^3/day used
(a)	Pump gland cooling		
•	Closed cycle cooling system	____________	____________
•	Once thru water segregated (not to process sewer)	____________	____________
•	Once thru non-segregated (goes to process sewer)	____________	____________
•	Other (List)		

____

____

____

____

____

____

(b)	Compressor Cooling	Number of compressors	M^3/day used
•	Closed cycle cooling system	____________	____________
•	Once thru water segregated (not to process sewer)	____________	____________
•	Once thru non-segregated (goes to process sewer)	____________	____________
•	Other (List)		

____

____

____

____

____

____

4.	Cooling Towers*	Summer	Winter
(a)	Make up water sources	______	______
(b)	Make up flow rate M^3/day	______	______
(c)	Make up water quality		
	Chlorides mg/L	______	______
	TDS mg/L	______	______
	Sulphates mg/L	______	______
	Silica mg/L	______	______
	Hardness as $CaCo_3$ mg/L	______	______
(d)	No. of cycles of concentration	______	______
(e)	Corrosion inhibitors used		
	Type	______	______
	Concentration	______	______
	Type	______	______
	Concentration	______	______
	Type	______	______
	Concentration	______	______
(f)	Blowdown Rate M^3/day	______	______
(g)	Blowdown quality		
	Chlorides mg/L	______	______
	TDS mg/L	______	______
	Sulphates mg/L	______	______
	Hardness as $CaCo_3$ mg/L	______	______
(h)	Cooling range Δc^{o}	______	______
(i)	Recirculation rate M^3/day	______	______
(j)	Evaporation rate M^3/day	______	______

*Note: If operating conditions in all your cooling towers are basically the same then they may be composited and only the above is necessary. If not, please make a separate sheet for each set of towers sharing a common pond under the tower.

5.	Overall Summary		Flow M^3/day	% of Total BTU Cooling Level
	(a)	Once thru water	______	______
	(b)	Recycled using cooling towers or ponds	______	______
	(c)	Air cooling	______	______

Are any wastewater flow reductions planned or under construction? Yes _____ No _____. If the answer is yes please describe the changes planned, when they will become effective and the amount of reduction expected.

E. SAMPLING AND MONITORING

- Use a separate page for each outfall
- Routine plant waste water, sampling exclusive of MISA
- For Frequency
    - 1/D = once per 24 hours
    - 1/W = once per week
    - 1/M = once per month

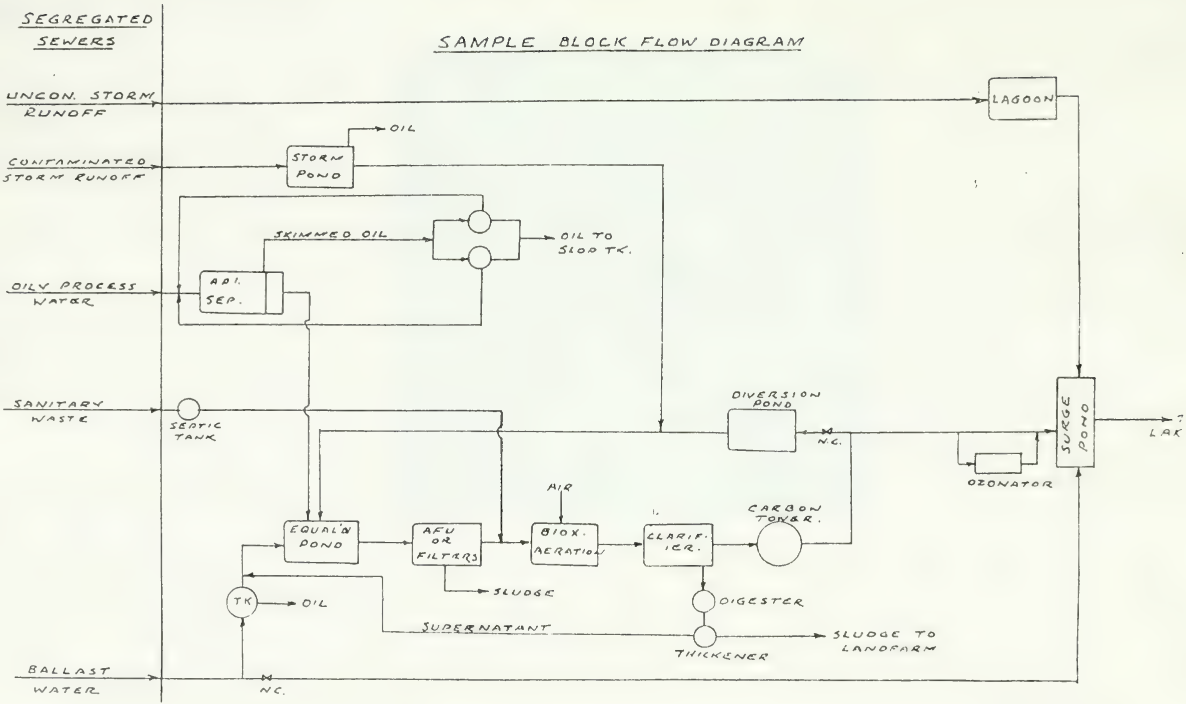
Parameter	Continuous Monitoring	Grab Sampling Frequency	Composite Sampling Frequency	Other Sampling Procedures
Oil & Grease				
Suspended Solids				
Ammonia N				
PH				
Phenolics				
Sulphides				
BOD				
TOC				
TOD				
Fish Toxicity				
Flow				
Explanations				

PHYSICAL DIMENSIONS OF EQUIPMENT

LIST ALL MAJOR PIECES OF WASTE WATER TREATMENT SUCH AS API SEPARATORS, EQUALIZATION PONDS, CLARIFIERS, BIOX. AERATION BASINS, ETC. USE ADDITIONAL SHEETS IF REQUIRED. SEE EQUIPMENT PERFORMANCE TABLE.

EQUIPMENT	DIMENSIONS	NORMAL FLOW M^3/day	EFFECTIVE VOLUME M^3	BRIEF OUTLINE OF DESIGN BASIS

SAMPLE BLOCK FLOW DIAGRAM



PART III

BEST AVAILABLE TECHNOLOGY OPTIONS FOR TREATMENT OF CHLORINATED DIBENZO-P-DIOXINS AND CHLORINATED DIBENZOFURANS IN ONTARIO PETROLEUM REFINERY CATALYTIC REFORMING WASTEWATERS

Prepared for:

Ontario Ministry of the Environment
MISA Program

JULY 1992

Science Applications International Corporation
Paramus, New Jersey

Amendola Engineering, Inc.
Lakewood, Ohio

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Appendix A CDDs and CDFs at Ontario Petroleum Refineries
Appendix B CDDs and CDFs at U.S. Petroleum Refineries
Appendix C Catalytic Reformer Wastewater Treatment Performance

INTRODUCTION

The Municipal/Industrial Strategy for Abatement Program (MISA) was established in 1986 with an ultimate goal to achieve "virtual elimination" of the discharge of persistent toxic pollutants. To advance toward that goal, the Ministry of Environment will establish a series of technology-based, sector-specific best available technology effluent limitations economically achievable BAT(EA) effluent limits regulations aimed at reducing and, where possible, eliminating the discharge of toxic and other pollutants. These effluent limitations will be based upon the actual or anticipated performance of a combination of process changes, in-plant and end-of-pipe control treatments, and source control measures.

The Ministry recognizes the following criteria for establishing BAT(EA):

a. Changes in production processes and raw materials that would eliminate or minimize introduction or formation of toxic chemicals;

b. Internal process recycle or reuse of waste materials for the purpose of minimizing or eliminating raw wastewater loadings of toxic pollutants;

c. Treatment and recycle of process wastewaters to minimize the volume of process wastewaters and the mass loadings of toxic pollutants requiring treatment;

d. End-of-pipe wastewater treatments to minimize or eliminate the mass discharge of toxic pollutants and the elimination of effluent toxicity to aquatic life.

In response to the Ministry's directive, this report sets out a proposal for Best Available Technology (BAT) for chlorinated dibenzo-p-dioxins (CDDs) and chlorinated dibenzofurans (CDFs) for the petroleum refining sector. The proposed BAT is based upon demonstrated internal treatment of catalytic refining wastewaters, which yields essentially non-detectable levels of CDDs and CDFs in petroleum refinery process wastewater effluent discharges.

This report is a supplement to the principal sector technical report:

Best Available Treatment Technology for the Petroleum Refining Sector, (SAIC, 1991).

1.0 Background

1.1 CDDs and CDFs

Polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans (CDDs and CDFs, respectively) are closely-related families of highly toxic and persistent organic chemicals which are formed as unwanted by-products in some commercially significant chemical reactions, during high temperature decomposition and combustion of certain chlorinated organic chemicals, and through other reactions involving chlorine and organic materials, (1,2,3,4,5).

Chlorinated dibenzo-p-dioxins (CDDs) and dibenzofurans (CDFs) constitute a family of over 200 related chemical compounds (congeners[1]) with varying chemical, physical, and toxicologic properties. The congener that appears to be the most toxic and has generally raised the greatest health concerns is 2,3,7,8-tetrachlorodibenzo-p-dioxin, abbreviated as 2378-TCDD.

Experimental studies with 2378-TCDD in animal systems have demonstrated a variety of toxic effects resulting from exposure to this compound (6). These effects include carcinogenesis, cancer promotion, reproductive and teratogenic effects, immunotoxic effects, thymus atrophy, liver damage, and effects on the skin and thyroid. Limited toxicological testing of other CDDs/CDFs has demonstrated that several of these compounds cause similar toxicologic effects, but that higher doses are generally required to cause effects of comparable magnitude to those induced by 2378-TCDD.

The evidence for the carcinogenic (cancer-causing) action of 2378-TCDD is provided mainly by several long-term studies of laboratory animals exposed to the substance. On the basis of these animal studies and associated factors, USEPA has concluded that 2378-TCDD is an animal carcinogen and should be regarded as a probable human carcinogen (6). USEPA is currently reviewing that assessment. 2378-TCDD has been shown to be teratogenic and to cause adverse reproductive effects in a number of animal species, including subhuman primates (7).

---

[1] The term "congener" refers to a specific compound within the same chemical family; e.g., there are 75 congeners of chlorinated dibenzo-p-dioxins (CDDs). The term "homologue" refers to a group of structurally related chemicals that have the same degree of chlorination; e.g., there are eight homologues of CDDs, monochlorinated through octochlorinated.

Unfortunately, CDDs and CDFs are among the most persistent as well as the most toxic pollutants. Certain congeners, including 2378-TCDD, are highly bioaccumulative and lipophilic. The U.S. Centers for Disease Control has estimated the half life of 2378-TCDD in the environment to be about twelve years. Thus, once introduced into the aquatic environment, certain CDDs and CDFs are likely to persist and bioaccumulate in fish and fish predators, including humans.

1.2 Mixtures of CDDs/CDFs

Studies have generally shown that most CDDs and CDFs cause similar effects to those caused by 2378-TCDD in the same bioassay systems, but that 2378-TCDD is the most potent. For purposes of dealing with mixtures of CDDs and CDFs, USEPA has adopted as interim science policy the "toxicity equivalence factor (TEF)" approach for use until sufficient additional data are available to derive a more accurate procedure that can be scientifically validated (8). The TEF approach uses correlations between structure and chemical activity to estimate the toxicity of any CDD/CDF mixture with regard to both carcinogenic and non-carcinogenic endpoints. The result is expressed as an equivalent amount of 2378-TCDD. For purposes of regulating mixtures of CDDs/CDFs, the Ministry of Environment has adopted the I-TEF approach, which has gained wide acceptance throughout the scientific community (9,10).

1.3 Findings of CDDs/CDFs at Petroleum Refineries

In December 1988, the Ministry announced findings of polychlorinated dibenzo-p-dioxins (CDDs) and polychlorinated dibenzofurans (CDFs) in an internal wastewater stream from the Shell Canada petroleum refinery located at Corunna (Sarnia), Ontario (11), (see Appendix A). These finding indicate that CDDs and CDFs originate in catalytic reforming operations. Catalytic reformers are used at nearly every major North American refinery to upgrade light petroleum distillates (low octane naphthas) to aromatics (high octane reformates) for use in blending of high octane gasolines and aviation fuels, or for recovery of specific aromatic compounds.

Catalytic reformers can be categorized by the type of catalyst regeneration system employed (12):

(1) ***Semi-Regenerative*** - Characterized by the shut down of the entire reforming unit at specified intervals for in situ regeneration of the catalyst. Regenerations are generally limited to one or two per year.

(2) ***Cyclic*** - Characterized by continual regeneration of the catalyst in situ in one of several reactors that is isolated from the naphtha feed during regeneration. The remaining reactors continue reforming naphtha while regeneration of the catalyst occurs in the isolated reactor. Generally, one of the reactors is operated in a regeneration mode. Thus, there may be several regeneration cycles each year.

(3) ***Continuous*** - A portion of the catalyst is continually removed from the reformer, regenerated in a separate reactor, and returned to the reformer.

In Ontario, six of the seven refineries have catalytic reformers. Those refineries have in total five semi-regenerative reformers, three continuous reformers and one cyclic reformer. In the U.S., 116 of 166 refineries, comprising 58 percent of U.S. reforming capacity, have semi-regenerative reformers, 27 refineries comprising 25 percent of reforming capacity have cyclic reformers; and 23 refineries comprising 17 percent of reforming capacity have continuous or other types of reformers (13).

In all cases, the purpose of catalyst regeneration is to remove accumulated coke from the catalyst under controlled combustion conditions and to replenish the catalyst with chlorine which is necessary for catalytic reactions to occur. Chlorine may be added in the form of chlorine gas, hydrochloric acid, or any of a number of chlorinated compounds including carbon tetrachloride, trichloroethane, dichloropropane, and dichloroethane. Reaction conditions of temperature, pressure and presence of free chlorine radicals and CDD and CDF precursors (various unchlorinated polycyclic compounds) are such that formation of CDDs and CDFs results during the catalyst regeneration cycle.

The off gases from the regeneration processes contain combustion products, hydrochloric acid, and water vapor. Depending upon design considerations (materials of construction, etc.) off gases may be scrubbed with a caustic or water solution, or vented directly to the atmosphere. Caustic scrubbing is more common at semi-regenerative reformers and generally not practiced at refineries with cyclic reformers.

2.0 Catalytic Reforming Operations - Ontario Refineries

As noted above, six of the seven Ontario refineries have catalytic reforming operations. The Novacor - Sarnia refinery does not produce high octane gasolines and thus is not equipped with a catalytic reformer.

Two refineries (Esso - Nanticoke, Petro Canada - Mississauga) have reformers with continuous catalyst regeneration not equipped with caustic or water scrubbers for neutralizing and treating regeneration off-gases. At Petro Canada - Mississauga the regeneration off gases are passed through a secondary furnace prior to discharge to the atmosphere. This may result in some destruction of CDDs and CDFs. Hence, there is no direct connection between the respective catalytic reforming operations and wastewater collection and treatment systems. For these refineries, some or all of the CDDs and CDFs that may be generated during catalyst regeneration are emitted to the atmosphere.

The Esso-Sarnia refinery has a cyclic reformer and a semi-regenerative reformer. Both are equipped with wet scrubbers. The Petro Canada - Oakville refinery has wet reformer off gas systems whereby water and caustic are injected into the off gasses prior to separation in a flash drum. The aqueous phase is discharged to the refinery wastewater treatment system. The Suncor refinery is equipped with two semi-regenerative reformers, each with wet off gas scrubbers. The Shell refinery is equipped with a continuous reformer with a caustic and water scrubber.

Table 1 presents the type of catalytic reformer at each Ontario refinery; the number of regenerations during 1989; the volume of contaminated water generated per regeneration; and, the estimated volume of contaminated water generated on an annual basis. The volumes of water generated per regeneration were obtained from industry data submitted to the Ministry.

3.0 Untreated Wastewater Quality

Upon discovery of CDDs and CDFs in catalytic reforming scrubber waters, the Ministry required that each refinery conduct in-plant and effluent monitoring to characterize generation and discharge of CDDs and CDFs. The Ministry and the Ontario Petroleum Association formed a committee to study the dioxin issue, conduct monitoring studies and investigate possible remedial actions. As part of that effort, the Ministry required that catalytic reforming wastewaters be stored until analyzed. Refinery monitoring data were confirmed by independent MOE analyses. The joint MOE/OPA program led to the development and implementation of temporary treatment facilities at the Shell and Suncor refineries.

A summary of the initial findings of CDDs and CDFs at the Shell refinery, and initial monitoring data from all refineries is presented in Appendix A. Limited available data obtained from U.S. EPA for three U.S. refineries are presented in Appendix B.

Table 1

**Catalytic Reforming Operations
Ontario Refineries**

Refinery	Type of Reformer	1989 Regenerations	Volume per Regeneration (US Gallons)	Volume per Year (US Gal)
Esso Nanticoke	Continuous	Continuous	N/A	N/A
Esso Sarnia	Cyclic Semi-Regen	16 - 18 1	484,000 1,500	8,710,000
Novacor Sarnia	N/A	N/A	N/A	N/A
Petro Canada Oakville *	Semi-Regen Semi-Regen	1 1	16,000 16,000	16,000 16,000
Petro Canada Mississauga	Continuous	Continuous	N/A	N/A
Shell Sarnia	Continuous	300	56,300	16,900,000
Suncor Sarnia	Semi-Regen Semi-Regen	1 2	10,000 40,000	10,000 80,000

* One catalytic reformer has been decommissioned.

4.0 Available Treatment Technologies - Design Considerations

4.1 MISA Objectives

The MISA approach to developing BAT(EA) has as its ultimate goal the virtual elimination of the discharge of persistent toxic pollutants. CDDs and CDFs are among the most persistent and the most toxic man-made pollutants. Accordingly, the development of BAT(EA) options that would make significant progress toward the goal of virtual elimination is a high priority of the Ministry. In working toward the goal of virtual elimination, the Ministry and the MISA Advisory Committee have recognized the following priorities for establishing BAT(EA), (14, 15):

a. Changes in production processes and raw materials that would eliminate or minimize introduction or formation of toxic chemicals;

b. Internal process recycle or reuse of waste materials for the purpose of minimizing or eliminating raw wastewater loadings of toxic pollutants;

c. Treatment and recycle of process wastewaters to minimize the volume of process wastewaters and the mass loadings of toxic pollutants requiring treatment;

d. End-of-pipe wastewater treatments to minimize or eliminate the mass discharge of toxic pollutants and the elimination of effluent toxicity to aquatic life.

Investigation of possible changes in catalytic reforming operations to eliminate or minimize formation of CDDs and CDFs would require a significant research and development effort, and a significant amount of time. Accordingly, this review focuses on process-specific wastewater treatment facilities to minimize the discharge of CDDs and CDFs at all refineries.

4.2 Pretreatment

4.2.1 Flow Reduction

As shown in Table 1, the largest volumes of contaminated catalytic reforming wastewaters are generated at the Esso - Sarnia refinery (Platformer #2 - cyclic reformer) and at the Shell - Sarnia refinery (continuous reformer). The cyclic reformer at the Esso-Sarnia refinery may be regenerated at two week intervals. Nearly 500,000 gallons (U.S.) are used for saturating and scrubbing the off gases to remove hydrochloric acid. At Shell, regenerations occur almost continuously. About 50 bbl. of spent caustic and 1000 bbl. of wash water are generated each day.

In each case there may be opportunities to minimize the volumes of scrubber waters requiring treatment by modifying the respective off-gas cooling and scrubbing systems. Depending upon materials of construction of existing systems, such modifications may entail significant rebuilds using corrosion resistant materials. For purposes of this report, the existing flows were used to develop proposed BAT(EA) effluent limitations and estimated costs. Notwithstanding, flow reduction is an integral part of the overall design of treatment facilities to ensure the most cost-effective facilities and lowest achievable mass discharges of CDDs/CDFs.

4.2.2. Isolation

Since available data from Ontario and U.S. refineries indicate the more toxic CDDs and CDFs are found only in wastewaters from catalytic reforming operations, the most effective means to achieve minimum mass discharge of these compounds is to isolate and treat the low volume catalytic reforming wastewaters prior to mixing with other refinery process or cooling waters, or storm waters. Accordingly, the catalytic reforming wastewaters should be collected and isolated at each refinery in appropriately sized equalization or holding tanks prior to treatment. The principal purposes of the holding or equalization tanks are to provide for temporary storage of reforming wastewaters and to provide for low volume constant feeds, thus allowing for design of downstream treatment systems at low hydraulic loading rates. This is possible only to a degree at the Esso - Sarnia and Shell refineries due to the large volumes of wastewaters requiring treatment.

Based upon investigations by Shell, catalytic reforming wastewaters are characterized by relatively low concentrations of very fine suspended particulates (16). CDDs and CDFs are most often associated with particulate matter in wastewater matrices. Hence, relatively simple technologies such as conventional gravity settling or mixed media filtration that are incapable of fine particulate removal would not be effective for removal of CDDs and CDFs from catalytic reforming wastewaters.

The more advanced adsorption and membrane technologies require fairly clean feed streams in terms of TSS to prevent fouling and plugging. Although it appears that untreated catalytic reforming wastewaters do not contain TSS at levels that are likely to cause operating problems in downstream units, consideration of pretreatment by filtration is recommended. Also, depending upon the reforming operation and the type of regeneration system and gas scrubbing system, the untreated wastewaters may be highly alkaline and unsuitable for direct feed to downstream treatment units. In these cases, neutralization with acid may be necessary.

In summary, pretreatment of catalytic reforming wastewaters should include reduction in flow, where possible; isolation; equalization or holding tanks; and, filtration and neutralization systems where necessary for protection of more advanced downstream treatment units.

4.3 Secondary Treatment

4.3.1 Wastewater Treatment in Other industries

There are few developed technologies available for removal of trace quantities of CDDs and CDFs from wastewater streams, and few instances where effluent limitations in the sub-parts per trillion range for these compounds have been established and implemented in wastewater discharge permits for industrial sources.

Dow Chemical at Midland, Michigan has an effluent limitation for 2378-TCDD of 8 parts per quadrillion (ppq) (17, 18). Sources of CDDs and CDFs at Dow include residual contamination from past manufacture of chlorinated phenolics, and hazardous waste incinerator emission control wastewaters from current operations. Dow found that much of the 2378-TCDD reaching the effluent discharge was associated with fine particulates originating in the incinerator scrubber waters. The fine particulates passed through end-of-pipe biological wastewater treatment facilities. Dow installed a mixed-media effluent filtration system, and subsequently an incinerator scrubber water pretreatment system consisting of chemically assisted clarification to control 2378-TCDD. Current discharge levels in Dow's total plant effluent (20 mgd) are less than 8 ppq, and generally in the range of ND(1) to 2 ppq (19).

Preliminary testing and treatability studies conducted by EPA for removal of 2378-TCDD and 2378-TCDF from bleached kraft pulp and paper mill wastewaters revealed that about 60 % of the 2378-TCDD and 2378-TCDF was associated with the aqueous phase of untreated bleachery wastewaters, which are high in organic content; and, that well over 90 % was associated with biological solids from activated sludge treatment systems (20). It was theorized that 2378-TCDD and 2378-TCDF were absorbed into or adsorbed onto the biological solids during biological treatment and removed with waste sludges. This work also demonstrated that high doses of various coagulants and polymers were effective at removing 2378-TCDD and 2378-TCDF from internal bleachery wastewaters by chemically assisted clarification. Related experiments conducted by the U.S. pulp and paper industry did not reveal other promising options using chemically assisted clarification or clarification assisted with other media (21).

Based upon the volumes of catalytic reformer wastewaters requiring treatment, the total suspended solids loading and particle size distribution, and the low organic loading, it appears that the more conventional treatments described above would either not be effective or would generate relatively large quantities of waste sludges from chemically assisted clarification that would require disposal. The solids would be principally comprised of coagulant.

4.3.2 Available Technologies

Other possible technologies, most of which have not been applied on a full scale basis for removal of CDDs and CDFs, include membrane separation (ultrafiltration, reverse osmosis), adsorption on granular activated carbon, solvent extraction and incineration. The merits of each technology are briefly reviewed below.

4.3.2.1 Membrane Technologies

Ultrafiltration and reverse osmosis are widely used in the pharmaceutical, pesticides and chemical process industries as well as in a number of other industries to perform separations of chemical species of varying molecular weight. It is highly likely that membranes are available to separate CDDs and CDFs from aqueous solutions. However, a principal drawback is that both technologies result in aqueous waste streams that contain the separated components and other compounds of similar molecular weight. The waste streams may range from 5 to 20 % of the original volumes processed and would require further processing to remove and fix the CDDs and CDFs for ultimate disposal. Hence, these technologies are not attractive from that standpoint.

4.3.2.2. Adsorption on Granular Activated Carbon

Adsorption on granular activated carbon offers several advantages over membrane technologies for removal of CDDs and CDFs from catalytic reforming wastewaters. The technology is suitable for treatment of relatively large volumes of wastewaters contaminated with adsorbable organic contaminants at low levels. Aside from spent carbon, there are no by-product sludges or concentrated aqueous streams requiring further processing or treatment for ultimate disposal. Multiple carbon units can be used in parallel or series to ensure maximum removal. Finally, since catalytic reformer wastewater streams are relatively low in organic content, the life of the carbon beds should be relatively long, on the order of a few years as opposed to weeks or months.

Shell and Suncor have installed temporary activated carbon treatment facilities and have applied for Certificates of Approval (C of A) for permanent wastewater treatment facilities. Treatability and performance data from these systems are summarized in Appendix C. These data indicate consistent high removal rates for CDDs and CDFs (> 95 %). Suncor recently reported consistent removal from current operations to non-detectable levels in the low parts per quadrillion range (ppq), which is generally considered state-of-the-art for analytical determinations (22,23). Shell reported more than 96 % removal during recent testing (24,25). All Ontario refineries have reported consistent non-detect levels of the more toxic CDD and CDF congeners in treated refinery process wastewater effluents (26).

4.3.2.3 Solvent Extraction

CDDs and CDFs are highly soluble in aromatic solvents. The standard analytical procedure for CDDs and CDFs in aqueous matrices includes a lengthy solvent extraction using benzene (27). Similar techniques could be applied to remove CDDs and CDFs from catalytic reforming wastewaters. The system would require a distillation step to recover the solvent for reuse, and a disposal method for the distillate bottoms would need to be developed. Disposal in refinery cracking operations may be feasible since the conditions present would favor destruction of CDDs and CDFs. This method offers the advantage of producing no solid or aqueous residuals requiring further processing, treatment or disposal; however, due to the large volumes of flow to be treated and the need for efficient extractions to ensure maximum removal, the investment and operating costs would likely be prohibitive.

4.3.2.4 Incineration

High temperature incineration can be used to destroy CDDs and CDFs at high efficiency. However, this technology is generally not feasible where relatively large volumes of wastewater must be processed as would be the case for treatment of catalytic reforming wastewaters, particularly at those refineries with continuous or cyclic reformers.

4.4 Post Treatment

In most instances, further treatment of catalytic reforming wastewaters in addition to the treatments described above are not necessary, particularly if treatment to non-detectable levels is possible. However, to ensure optimum removal, protection from breakthrough of secondary treatment, and protection for possible spills, treated catalytic reforming wastewaters should be co-mingled with other refinery wastewaters and processed in the existing end-of-pipe treatment facilities. Any remaining CDDs and CDFs present in the catalytic reforming wastewaters will likely be removed with tramp oils or absorbed or adsorbed onto biological solids in the activated sludge systems and removed with the waste sludges.

5.0 Proposed Best Available Technology Effluent Limitations and Monitoring Requirements

5.1 Technology Trains

Based upon the above assessment of available technologies, only one wastewater treatment technology train appears to be feasible for the Ontario refineries. This train is proposed for development of Best Available Technology (Economically Achievable) effluent limitations.

The technology train includes the following major components:

Pretreatment

- isolation of catalytic reforming wastewaters;
- flow reduction should be accomplished, where possible;
- equalization and holding tank; and,
- neutralization and filtration, if necessary.

Secondary Treatment

- adsorption on two granular activated carbon units operated in series;
- curbing and diking of the equalization tank and treatment facility area.

Post Treatment

- treated wastewaters co-mingled with other refinery wastewaters and co-treated in existing end-of-pipe wastewater treatment facilities, including biological treatment.

A single technology train was specified for the following reasons:

1. At this time, information to specify process modifications to eliminate formation of CDDs and CDFs during regeneration of catalytic reforming catalysts is not available.

2. Alternate treatment technologies for removal of sub-part per trillion levels of CDDs and CDFs from wastewaters are not well developed. Data for activated carbon treatment at Ontario refineries show consistent high removals.

3. The technology recommended for consideration is suitable for treatment of the particular wastewater streams under review, and, except for Shell, would result in non-detectable levels in catalytic reforming wastewaters prior to mixing with other refinery wastewaters. Thus, implementation of this technology would be consistent with advancing toward the MISA goal of virtual elimination.

5.2 Proposed Effluent Limitation

Based upon treatability results developed by Ontario refineries, the following proposed effluent limitation is recommended for consideration by the Joint Technical Committee:

Monitoring Point	Effluent Limitations
Final refinery process wastewater effluent, prior to mixing with non-contact cooling and storm water.	2378-TCDD TEQs ND (10) ppq

5.3 Proposed Monitoring Requirements

The proposed frequency of monitoring for compliance is different for each type of refinery as set out below:

	Monitoring Point	Monitoring Frequency	
		Esso - Sarnia Shell - Sarnia	Petro-Canada - Oakville Suncor Sarnia
1.	Influent to catalytic reforming treatment facility.	1/month	1/regen.
2.	Discharge from catalytic reformer wastewater treatment facility, prior to mixing with other refinery wastewaters.	1/month	1/regen.
3.	Final refinery process wastewater effluent, prior to mixing with non-contact cooling and storm water.	1/month	1/regen.
4.	API separator sludge and waste biological sludge.	2/year	2/year

Monitoring of internal streams (untreated and treated catalytic reforming wastewaters prior to mixing with other refinery wastewaters) is proposed to ensure proper operation of the treatment facilities, and to document the fate of the CDDs and CDFs that are generated.

All wastewater and sludge samples taken should be composite samples. For Esso - Sarnia and Shell, the composite wastewater samples should be comprised of at least 12 sample increments taken over a 48 hour period during a catalyst regeneration cycle. For Petro-Canada (Oakville) and Suncor, the composite wastewater samples should be made up of at least six sample increments obtained during 24 hours of operation of the respective catalytic reforming treatment systems. Refinery final process wastewater effluent sampling should be staged to account for and overlap the residence time in the end-of-pipe wastewater treatment facilities. Sludge samples should be short-term composites obtained during an operating shift.

The analytical methods used for determination of CDDs and CDFs should include high resolution GC/MS, or alternatively, HPLC separations followed by medium or low resolution analytical systems. The methods must be capable of determining 2378-substituted CDDs and CDFs at low parts per quadrillion (ppq) detection levels in wastewater samples, and low parts per trillion (ppt) in sludge samples.

5.4 Estimated Costs of Compliance

Shell and Suncor have completed preliminary engineering and developed the following estimated investment and annual operating costs for wastewater treatment facilities as outlined above for BAT(EA) (28,29):

REFINERY	INVESTMENT COST	ANNUAL OPERATING COST
SHELL - SARNIA	$ 2,000,000	$ 200 - 300,000
SUNCOR - SARNIA	200,000	N/A

The Shell estimate includes about $500,000 for an acid neutralization system, which Shell reports may or may not be necessary. Given that the volumes of wastewaters requiring treatment at Esso and Petro-Canada are in the same range as those for Shell and Suncor, respectively, investment and annual operating costs for those refineries are likely to be similar.

REFERENCES

1. Esposito, M.P., Tiernan, T.O. and Dryden, F.E., ***Dioxins***, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio, EPA-600/2-80-197, November 1980.

2. U.S. Environmental Protection Agency, ***National Dioxin Study Report to Congress***, Office of Solid Waste and Emergency Response, Washington, D.C., August 1987, EPA/530-SW-87-025.

3. U.S. Environmental Protection Agency, ***The National Dioxin Study - Tiers 3,5,6, and 7***, Office of Water Regulations and Standards, Washington, D.C., February 1987, EPA-440/4-87-003.

4. Amendola, G.A., Barna, D., Blosser, R., LaFleur, L., McBride, A., Thomas, F., Tiernan, T., and Whittemore, R., ***The Occurrence and Fate of PCDDs and PCDFs in Bleached Kraft Pulp and Paper Mills***, *Chemosphere*, Volume 18, Nos. 1 - 6, 1989.

5. U.S. Environmental Protection Agency, ***U.S. EPA/Paper Industry Cooperative Dioxin Screening Study***, Office of Water Regulations and Standards, Washington, D.C., March 1988, EPA 440/1-88-025.

6. U.S. Environmental Protection Agency, ***Health Assessment Document for Polychlorinated Dibenzo-p-Dioxins***, Office of Research and Development, Washington, D.C., September 1985, EPA 600/8-84-014F.

7. U.S. Environmental Protection Agency, ***Guidelines for Carcinogen Risk Assessment***, 51 FR 33992-34003, 1986.

8. Bellin, J.S. and Barnes, D.G., ***Interim Procedures for Estimating Risks Associated with Exposures to Mixtures of Chlorinated Dibenzo-p-Dioxins and -Dibenzofurans (CDDs and CDFs)***, U.S. Environmental Protection Agency, March 1987, EPA 625/3-87/012.

9. North Atlantic Treaty Organization, Committee on the Challenges of Modern Society, ***Pilot Study on International Information Exchange on Dioxins and Related Compounds: International Toxicity Equivalence Factor (ITEF) Method of Risk Assessment for Complex Mixtures of Dioxins and Related Compounds***, Report Number 176, August 1988.

10. Bellin, J.S. and Barnes, D.G., ***Interim Procedures for Estimating Risks Associated with Exposures to Mixtures of Chlorinated Dibenzo-p-Dioxins and -Dibenzofurans (CDDs and CDFs) and 1989 Update***, U.S. Environmental Protection Agency, March 1989, EPA 625/3-89/016.

REFERENCES

11. Communique: ***MISA Monitoring Discovers Dioxins and Furans in Wastewater Stream of Petroleum Refinery***; Ontario Ministry of the Environment; Toronto, Ontario, Canada; December 5, 1988.

12. Myers, R.A., ***Handbook of Petroleum Refining Processes***, McGraw-Hill Inc., 1986.

13. Gwyn, D.A., ***Annual Refining Survey***, *Oil and Gas Journal*, March 20, 1989.

14. Ontario Ministry of the Environment, ***MISA Issues Resolution Process, Issue Resolution Committee Reports***, Water Resources Branch, Toronto, Ontario, June 1990.

15. Communication: ***MISA Issues Resolution Committee Reports***; To: The Honorable Jim E. Bradley, Minister of the Environment, Toronto, Ontario; From: Dr. Isobel Heathcote, Chair for the MISA Advisory Committee, Toronto, Ontario; August 20, 1990.

16. Masters, D.P., ***Carbon Adsorption of Dioxins from Spent Caustic, SMC PER 89-001***, Process Engineering - Sarnia Manufacturing Centre, Shell Canada Ltd., Sarnia, Ontario, October 1989.

17. ***Final Order of Abatement 2120 - Dow Chemical Company, Michigan Division, Midland Michigan***, Water Resources Commission, Department of Natural Resources, State of Michigan, Lansing, Michigan, September 15, 1988.

18. ***NPDES Permit MI0000868 - Dow Chemical Company, Michigan Division, Midland, Michigan***, Michigan Water Resources Commission, Lansing, Michigan, October 3, 1988.

19. Personal Communication with Mr. Randy M. Croyle, Manager, Environmental Services, Dow Chemical Company, Michigan Division, Midland Michigan, Decemeber 11, 1990.

20. Amendola, G.A., Bodien, D.G. and Handy, R.E., ***Bench Scale Study of 2378-TCDD and 2378-TCDF Treatability in Pulp and Paper Mill Wastewaters***, *TAPPI Journal*, Vol.72, No. 12, 1989.

21. Barton, D.A., McKeown, J.J. and Brunck, R., ***A Screening Study of the Treatability of Dioxins and Furans in Bleach Plant Filtrates and Mill Wastewaters***, National Council of the Pulp and Paper Industry for Air and Stream Improvement, Inc., Medford, Massachusetts, Presented at: *Dioxin '89*, Toronto, Ontario, September 1989, Accepted for Publication in *Chemosphere*.

REFERENCES

22. Communication: To: Mr. L. Van Asseldonk, Ministry of the Environment, Sarnia, Ontario; From: Mr. T. A. Brown, SUNOCO INC., Sarnia, Ontario, October 18, 1990.

23. Personal Communication with Mr. Thomas A. Brown, SUNOCO INC., Sarnia, Ontario, November 1, 1990.

24. Personal Communication with Mr. Dana Atwell, Process Engineering Supervisor - Environmental/Industrial Hygiene, Sarnia Manufacturing Complex, Shell Canada Products Limited, Sarnia, Ontario, November 1, 1990.

25. Communication: To: Mr. Al Peterson, Ministry of the Environment, Sarnia, Ontario; From: Dana Atwell, Environmental Manager, Shell Canada Products Limited, Sarnia, Ontario, June 26, 1991.

26. Ministry of the Environment, Water Resources Branch, ***Second Report on the Monitoring Data for the Petroleum Refining Sector***, July 1990, ISBN 0-7729-7331-8.

27. USEPA, ***Method 1613: Tetra- through Octa-Chlorinated Dioxins and Furans by Isotope Dilution***, Industrial Technology Division, Office of Water Regulations and Standards, Office of Water, Washington, D.C., July 1989.

28. Personal Communication with Mr. Dana Atwell, Process Engineering Supervisor - Environmental/Industrial Hygiene, Sarnia Manufacturing Complex, Shell Canada Products Limited, Sarnia, Ontario, November 6, 1990.

29. Personal Communication with Mr. Thomas A. Brown, SUNOCO INC., Sarnia, Ontario, November 8, 1990.

APPENDIX A

CDDs AND CDFs AT ONTARIO PETROLEUM REFINERIES

Appendix A

SHELL CANADA PRODUCTS LIMITED
SARNIA REFINERY

Range of Dioxins/Furans in Internal Shell Wastewaters
(All Figures in Parts Per Billion)

Sample	New Caustic	Spent Caustic	Scrubber Water	Biological Sludge	Combined Effluent
2,3,7,8,8-4 CDD	ND**	0.0046 - 0.0054	ND	ND	ND
4CDD (Total)	ND	0.350 - 5.900*	0.0052 - 0.012	9.9 - 15	ND
5CDD	ND	0.400 - 8.200*	0.00076 - 0.002	9.0 - 17	ND
6CDD	ND	0.530 - 5.300*	0.00076 - 0.0012	17.0 - 23	ND
7CDD	ND	0.290 - 1.500*	0.00091 - 0.0014	8.7 - 12	ND
8CDD	ND	0.230 - 1.300*	0.00052 - 0.00071	7.0 - 8.4	ND
Total Dioxins ***		1.810 - 22.200	0.00815 - 0.01731	51.6 - 75.4	
4CDF	ND	0.380 - 6.1*	0.0051 - 0.010	8.2 - 10.0	ND
5CDF	ND	0.680 - 8.9*	0.0016 - 0.0038	12.0 - 16.0	ND
6CDF	ND	1.200 - 5.6*	0.0031 - 0.0057	24.0 - 31.0	ND
7CDF	ND	1.400 - 4.2*	0.0049 - 0.0084	28.0 - 40.0	0.00034 to 0.00022
8CDF	ND	0.760 - 2.5*	0.00071 - 0.0008	20.0 - 28.0	ND
Total Furans ***		4.420 - 27.3	0.01541 - 0.0287	92.2 - 125	

* July Shell samples; other are November samples taken by ministry; all November samples were done in duplicate

** Non-Detectable

*** Totals may not add because highest and lowest concentrations for individual types of dioxins and furans did not occur in same samples.

Appendix A

ESSO PETROLEUM CANADA
SARNIA REFINERY

POWERFORMER REGENERATION STUDY

Dioxin and Furan Concentrations - December 16, 1988
(Parts Per Trillion)

PCDF/PCDD Isomer Group	Scrubber Water		BIOX Inlet		BIOX Outlet	
	First 24 Hours	Second 24 Hours	First 24 Hours	Second 24 Hours	First 24 Hours	Second 24 Hours
2378-TCDD	<0.005	<0.012				
4-TCDD	0.11	0.111	<0.002	<0.009	<0.003	<0.008
5-PCDD	0.030	0.072	<0.005	<0.005	<0.008	<0.004
6-HCDD	0.015	0.027	<0.004	<0.007	<0.007	<0.004
7-HCDF	0.042	0.041	<0.04	<0.02	<0.01	<0.01
8-OCDF	0.037	0.063	<0.04	<0.06	<0.03	<0.03
Total Dioxins	0.243	0.308	0.000	0.000	0.000	0.000
4-TCDF	0.32	0.48	<0.002	0.051	<0.002	<0.002
5-PCDF	0.14	0.17	<0.003	0.029	<0.008	<0.004
6-HCDF	0.071	0.11	<0.02	<0.007	<0.006	<0.002
7-HCDF	0.026	0.077	<0.01	<0.008	<0.007	<0.004
8-OCDF	0.071	0.21	<0.02	<0.03	<0.02	<0.02
Total Furans	0.628	1.038	0.000	0.080	0.000	0.000
2378-TCDD Toxic Equivalent	0.243	0.345	0.000	0.040	0.000	0.000

* 4-TCDD includes 2378-TCDD

* Totals and toxic equivalents do not include values below MDL. Assume less than detectable means zero.

INITIAL TESTING FOR CDDs/CDFs

ONTARIO PETROLEUM REFINERIES

Refineries with Wet Scrubbers

Refinery	Reformer	Type	Date	2378-TCDD TEQ In Scrubber Effluents
Esso-Sarnia	#1	Cyclic	12/88	240-440 ppt
	#2	Semi-regenative	2/89	300 ppt
Petro Canada - Missasauga	#1	Semi-regenative	12/88	0.15 ppt
Shell-Sarnia		Continuous	7/88	9,530 ppt NaOH
			11/89	920 ppt
			2/89	300 ppt
			4/89	2,000 ppt
Suncor-Sarnia	#1	Semi-regenative	6/89	9-167 ppt water 213 ppt NaOH
	#2	Semi-regenative	4/89	44-415 ppt water 187 ppt NaOH

Refineries with No Scrubbers

Refinery	Reformer	Estimated Maximum Ground Level Concentration 2378-TCDD-TEQ
Petro Canada-Oakville	Continuous	0.7 picograms/m^3
Esso-Nanticoke	Continuous	0.042 picograms/m^3

MOE Provisional Guideline is 450 picograms/m^3 (30 minute average)

APPENDIX B

CDDs AND CDFs AT U.S. PETROLEUM REFINERIES

Appendix B

CDDs/CDFs AT U.S. PETROLEUM REFINERIES

UNTREATED CATALYTIC REFORMER WASTEWATERS

FACILITY B

(Parts Per Trillion)

	Solid	Filtrate	Total(1)
2,3,7,8-TCDD	ND	ND	ND
Total TCDD	ND	ND	ND
2,3,7,8-TCDF	ND	ND	ND
Total TCDF	ND	ND	ND
Total CDD's	0.089-5.03	ND-0.278	0.132- 3.22
Total CDF's	ND-2.1	ND-0.982	ND- 2.12
2378-TCDD TEQ(2,3)			0.11-18.9

FACILITY C

(Parts Per Trillion)

	Solid	Filtrate	Total
2,3,7,8-TCDD	ND- 7.1	ND- 0.97	ND - 7.48
Total TCDD	0.11- 89.7	ND-10.9	0.11 - 100.6
2,3,7,8-TCDF	0.03- 21.3	ND- 1.2	0.03 - 22.5
Total TCDF	0.14- 576	0.008-38.3	0.148- 612.2
Total CDD's	3.11- 183.8	0.12 -24.06	3.2 - 198.4
Total CDF's	2.58-1145.29	0.83 -67.97	3.66 -1011.3
2378-TCDD TEQ(2,3)			0.12 - 57.3

Notes:
(1) The solid and liquid portions of each ample were separated and anlayzed separately.
(2) 2378-TCDD TEQ computed from *Procedures for Estimating Risk Associated with Exposures to Mixtures of Chlorinated Dibenzo-p-Dioxins and -Dibenzafurans (CDDs & CDFs)* EPA/625/3/-89/016, March 1989.
(3) 2378-TCDD TEQ results in parts per quadrillion.

CDDs/CDFs AT U.S. PETROLEUM REFINERIES

API OIL SEPARATOR SLUDGE

(Parts Per Trillion)

	Facility A(1,2)	Facility B	Facility C
2,3,7,8-TCDD	ND(1)	ND	ND
Total TCDD	ND	ND	21
2,3,7,8-TCDF	ND	48	2.4
Total TCDF	ND	73	11.8
Total CDD's	ND	790	4567.2
Total CDF's	ND	1653	319.4
2378-TCDD TEQ(3)	0	50.08	11.63

Notes:

(1) The first wastewater stream sampled downstream of the process at Facility A was API separator effluent. There were no detectable CDDs or CDFs.

(2) The sludge from the biological treatment unit at Facility A indicated 144.5 ppt Total CDD and 2.5 ppt Total CDF.

(3) 2378-TCDD TEQ results in parts per quadrillion.

APPENDIX C

CATALYTIC REFORMER WASTEWATER TREATMENT PERFORMANCE

SUNCOR-SARNIA
CATALYTIC REFORMER WASTEWATER TREATMENT

August 3, 1990 Samples

	Results in Parts Per Trillion (ppt)	
	Carbon Filter Influent	Carbon Filter Effluent
2378-TCDD	ND (10)	ND (10)
TCDDs	260	ND (10)
PeCDDs	310	ND (10)
HxCDDs	700	ND (20)
HpCDDs	210	ND (30)
OCDD	83	ND (30)
2378-TCDF	300	ND (10)
TCDFs	1,400	ND (10)
PeCDFs	2,000	ND (10)
HxCDFs	3,900	ND (10)
HpCDFs	1,300	ND (20)
OCDF	530	ND (20)
2378-TCDD TEQ(2)	2,520	34.5
Removal Efficiency		> 98.6%

Notes (1) Source: October 18, 1990 letter from T.A. Brown, Suncor to L. Van Asseldonk, MOE-Sarnia.

(2) 2378-TCDD TEQ computed assuming CDDs and CDFs were present at detection levels when not-detected results obtained.

Appendix C

SHELL CANADA-SARNIA

CATALYTIC REFORMER WASTEWATER TREATMENT
SPENT CAUSTIC

May 9, 1991

Results in Parts Per Trillion (ppt)

	Carbon Filter Influent	Carbon Filter Effluent
2378-TCDD	< 5.5	0.21
TCDDs	95	5.9
12378-PeCDD	15	0.3
PeCDDs	120	7.3
123478-HxCDD	8.5	0.35
123678-HxCDD	25	0.8
123789-HxCDD	< 5.8	0.84
HxCDDs	140	8
1234678-HpCDD	86	3.9
HpCDDs	140	7.2
OCDD	90	4.7
2378-TCDF	54	0.43
TCDFs	210	8.5
12378-PeCDF	13	1.6
23478-PeCDF	27	1.3
PeCDFs	350	16
123478-HxCDF	220	9.2
123678-HxCDF	120	3.5
234678-HxCDF	47	1.8
123799-HxCDF	27	< 0.057
HxCDFs	580	28
1234678-HpCDF	400	18
1234789-HpCDF	69	3.2
HpCDF	590	29
OCDF	260	15
2378-TCDD TEQ	431	4.54
Removal Efficiency		98.9%

Note (1) Source: June 26, 1991 letter from D. Atwell, Shell Canada to A. Peterson, MOE-Sarnia